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3 Building Envelope Requirements

3.1 Overview

This chapter covers building envelope features and compliance strategies and highlights the Energy Code requirements that affect the design of the building envelope for newly constructed single family residential buildings. See Chapter 9 for information on alterations and additions.

The design of envelope components can significantly affect the energy demand needed to meet heating and cooling loads to maintain the desired internal building temperature.

Heating and cooling load calculations are used to determine the mechanical system design needed for space heating and cooling.

- **Heating Loads:** The principal components of heating loads are infiltration and conduction losses through building envelope components, including walls, roofs, floors, slabs, windows, and doors.
 - **Example:** A dwelling unit located in climate zone 16 typically has a large heating load due to moderate summers, cool temperatures, and snow cover that predominates for more than half of the year.
- **Cooling Loads:** Cooling loads are dominated by solar gains through windows, skylights, and roof/attic assemblies.
 - **Example:** A dwelling unit located in climate zone 15 typically has a large cooling load due to extremely hot and dry summers and moderately cold winters.

3.1.1 Navigating This Chapter

This chapter is organized by building envelope component as seen in the Table of Contents.

This chapter includes:

- An overview of changes to building envelope requirements for the 2022 Energy Code
- A description of fenestration terminology, requirements and labeling, U-factor and solar heat gain coefficient (SHGC) requirements, and credits that can be used under the performance approach
- Description of opaque envelope terminology, requirements related to insulation, roof products, radiant barriers, air barriers, vapor retarders, and attic ventilation

- Compliance approaches for alternative construction assemblies such as log homes, straw bale, structural insulated panels (SIPs) and insulated concrete form (ICF) construction

3.2 New Envelope Requirements for 2022

The *2022 Building Energy Efficiency Standards* for residential buildings include increased efficiencies for several envelope requirements, and there are improvements that have been made to better aid the designer, builder, and building official.

MANDATORY §150.0

- Mandatory roof deck insulation in newly constructed attic systems in Climate Zones 4 and 8-16 to meet an area-weighted average U-factor no greater than 0.184.
- Mandatory minimum U-factor for Fenestration products including skylight decreased to 0.45

3.3 Fenestration (Window/Skylight/Glazed Door) and Opaque Doors

Fenestration products such as windows, glazed doors, dynamic glazing, window films, and skylights have a significant impact on energy use and heating and cooling loads in a home. The size, orientation, and types of fenestration products can dramatically affect the overall energy performance of a house. Glazing type, orientation, shading, and shading devices not only play a major role in the energy use of a building, but can affect the operation of the lighting system, HVAC system, and comfort of occupants.

Table 3-1 Relevant Sections in the Energy Code

	MANDATORY	PRESCRIPTIVE	PERFORMANCE
Fenestration and Opaque Doors	§10-111, §10-112, §110.6, §150.0(q), Tables 110.6-A and 110.6-B	§150.1(c)3, §150.1(c)4, §150.1(c)5 Table 150.1-A	§150.1(a), §150.1(b)
Limit Air Leakage	§110.7	-	-

Source: California Energy Commission

3.3.1 Fenestration Types

3.3.1.1 Windows and Glazed Doors

A window is a vertical fenestration product that is an assembled unit consisting of a frame and sash component holding one or more pieces of glazing. Window performance is measured with the U-factor and solar heat gain coefficient (SHGC).

Glazed doors are an exterior door having a glazed area of 25 percent or more of the area of the door. Glazed doors are treated the same as windows and must meet the U-factor and SHGC requirements for windows. Most sliding glass doors, French doors, and some entry doors with large amounts of glazing will meet the definition to be treated as glazed doors.

3.3.1.2 Opaque Doors

When the door has less than 25 percent glazing material, it is considered an opaque door and is subject to the door U-factor requirements. Doors between the garage and conditioned space that are required to have fire protection are not required to meet the U-factor requirement.

3.3.1.3 Skylights and Tubular Daylight Devices

Skylights and tubular daylight devices (TDD) are an exceptional source of daylight and passive solar heating, illuminating rooms with direct and indirect sunlight. When used appropriately, daylighting can increase the quality of light in a room and reduce dependence upon electrical lighting.

Skylights and TDDs don't typically have the same thermal properties as vertical fenestration and can be prone to greater heat loss in winter and solar heat gain during the summer. When a building designer optimizes the whole envelope glazing arrangement for daylight and thermal control, significant heating and cooling energy savings can be realized, especially when skylights and TDDs are as efficient as other vertical windows used.

Windows are considered part of an exterior wall when the slope is 60° or more as measured from the horizontal. Where the slope of fenestration is less than 60°, the glazing indicated as a window is considered a skylight and part of the roof.

3.3.1.4 Fenestration Subcategories

- A. **Manufactured fenestration** is a fenestration product constructed of materials that are factory-cut or otherwise factory-formed with the specific intention of being used to fabricate a fenestration product. Knocked down or partially assembled products may be sold as a fenestration product when provided with temporary and permanent labels, as described in §10-111, or as a site-built fenestration product when not provided with temporary and permanent labels, as described in §10-111.
- B. **Site-built fenestration** is designed to be field-glazed or field-assembled units, using specific factory-cut or other factory-formed framing, and glazing units that

are manufactured with the intention of being assembled at the construction site. These include storefront systems, curtain walls or large-track sliding glass walls, and atrium roof systems.

- C. **Field-fabricated fenestration** is when the windows are fabricated at the building site from elements that are not sold together as a fenestration product (that is, separate glazing, framing, and weatherstripping elements). Field-fabricated does not include site-assembled frame components that were manufactured elsewhere with the intention of being assembled on site (such as knocked-down products, sunspace kits, and curtain walls).

3.3.1.5 Fenestration Definitions

- A. **Center of glass.** U-factor, solar heat gain coefficient (SHGC), and visible transmittance (VT) are measured only through glass at least 2.5 inches from the edge of the glass or dividers.
- B. **Clear glass** has little, if any, observable tint with an insulated glass (IG) unit with an SHGC of 0.5 or greater.
- C. **Chromogenic** is a class of glazing that can change the optical properties by including active materials (e.g., electrochromic) and passive materials (e.g., photochromic and thermochromic) permanently integrated into the glazing assembly.
- *Electrochromatic* is a class of glazing that tints on demand using a small amount of electricity.
- D. **Divider (muntin).** An element that physically or visually divides different lites of glass. (See Definition K.) It may be a true divided lite, between the panes, or applied to the exterior or interior of the glazing.
- E. **Double-pane window.** Double-pane (or dual-pane) glazing is made of two panes of glass (or other glazing material) separated by space (generally ¼" [6 mm] to ¾" [18 mm]) filled with air or other gas. Two panes of glazing laminated together do not constitute double-pane glazing.
- F. **Dynamic glazing.** Glazing systems that have the ability to reversibly change the performance properties, including U-factor, solar heat gain coefficient (SHGC), and/or visible transmittance (VT) between well-defined end points. Includes active materials (e.g., electrochromic) and passive materials (e.g., photochromic and thermochromic) permanently integrated into the glazing assembly.

With appropriate controls, electrochromic glass can be darkened or lightened to adjust the levels of daylight and solar heat gain. These products have the ability to reversibly change the SHGC and VT between well-defined endpoints.

Integrated shading systems is a class of fenestration products including an active layer (e.g., shades, louvers, blinds, or other materials) permanently

integrated between two or more glazing layers and that has the ability to reversibly change performance properties, including U-factor, SHGC, and/or VT between well-defined end points.

- G. **Fixed.** The fenestration product cannot be opened.
- H. **Gap width.** The distance between glazing in multi-glazed systems (e.g., double or triple glazing). This dimension is measured from inside surface to inside surface. Some manufacturers may report "overall" IG unit thickness, which is measured from outside surface to outside surface.
- I. **Grille.** See Divider.
- J. **Insulating glass unit (IG unit or IG).** An IG unit includes the glazing, coatings, tinting, spacer(s), films (if any), gas infills, and edge caulking.
- K. **Light or lite.** A layer of glazing material, especially in a multilayered IG unit. Referred to as panes in §110.6 when the lites are separated by a spacer from inside to outside of the fenestration.
- L. **Low emissivity (Low-e) coatings.** Low-e coatings are special coatings applied to the second, third, or fourth surfaces in double-glazed windows or skylights. As the name implies, the surface has a low emittance, meaning that radiation from that surface to the surface it "looks at" is reduced. Since radiation transfer from the hot side to the cool side of the window is a major component of heat transfer in glazing, low-e coatings are very effective in reducing the U-factor. They do nothing, however, to reduce losses through the frame.

Low-e coatings can be engineered to have different levels of solar heat gain. Generally, there are two kinds of low-e coatings:

1. Low-solar-gain low-e coatings are formulated to reduce air-conditioning loads. Fenestration products with low-solar-gain low-e coatings typically have an SHGC of 0.40 or less. Low-solar-gain low-e coatings are sometimes called *spectrally selective coatings* because they filter much of the infrared and ultraviolet portions of the sun's radiation while allowing visible light to pass through.
2. High-solar-gain low-e coatings, by contrast, are formulated to maximize solar gains. Such coatings would be preferable in passive solar applications or where there is little air conditioning.

Another advantage of low-e coatings, especially low-solar-gain low-e coatings, is that when they filter the sun's energy, they generally remove between 80 percent and 85 percent of the ultraviolet light that would otherwise pass through the window and damage fabrics and other interior furnishings. This is a major advantage for homeowners and can be a selling point for builders.

- M. **Mullion.** A frame member that is used to join two windows into one fenestration unit.
- N. **Muntin.** See Dividers.
- O. **Nonmetal frame.** Includes vinyl, wood, fiberglass, and other low-conductance materials. Vinyl is a polyvinyl chloride (PVC) compound used for frame and divider elements with a significantly lower conductivity than metal and a similar conductivity to wood. Fiberglass has similar thermal characteristics. Nonmetal frames may have metal strengthening bars entirely inside the frame extrusions or metal-cladding only on the surface.
- P. **Operable.** The fenestration product can be opened for ventilation.
- Q. **Solar heat gain coefficient (SHGC).** A measure of the relative amount of heat gain from sunlight that passes through a fenestration product. SHGC is a number between zero and one that represents the ratio of solar heat that passes through the fenestration product to the total solar heat that is incident on the outside of the window. A low SHGC number (closer to 0) means that the fenestration product keeps out most solar heat. A higher SHGC number (closer to 1) means that the fenestration product lets in most of the solar heat.

SHGC or SHGC_t is the SHGC for the total fenestration product and is the value used for compliance with the Energy Code.
- R. **Spacer or gap space.** A material that separates multiple panes of glass in an IG unit.
- S. **Thermal break frame.** Includes metal frames that are not solid metal from the inside to the outside but are separated in the middle by a material with a significantly lower conductivity.
- T. **Tinted.** Glazing products formulated to have the appearance of color that alters the solar heat gain and visible transmittance. Common colors include gray, bronze, green, and blue. Some coatings can also appear tinted.
- U. **U-factor.** A measure of how much heat can pass through a construction assembly or a fenestration product. The lower the U-factor, the more energy efficient the product is. The units for U-factor are British thermal units (Btu) of heat loss each hour per square foot (ft²) of window area per degree Fahrenheit (°F) of temperature difference (Btu/hr-ft²-°F). U-factor is the inverse of R-value.

The U-factor considers the entire product, including losses through the center of glass, at the edge of glass where a metal spacer typically separates the double-glazing panes, losses through the frame, and through the mullions. For metal-framed fenestration products, the frame losses can be significant.
- V. **Visible transmittance (VT)** is the ratio of visible light transmitted through the fenestration. The higher the VT rating, the more light is allowed through a window.

W. **Window films** are composed of a polyester substrate to which a special scratch-resistant coating is applied on one side, with a mounting adhesive layer and protective release liner applied to the other side.

3.3.2 Mandatory Requirements §10-111, §10-112, §110.6

3.3.2.1 Fenestration Products and Labeling §10-111; §110.6(a)5

The National Fenestration Rating Council (NFRC) is the entity recognized by the California Energy Commission to supervise the rating and labeling of fenestration products. NFRC maintains the Certified Product Directory, containing NFRC certified U-factors, SHGC and VT values for thousands of fenestration products, on its [website](http://www.nfrc.org) at <http://www.nfrc.org>.

Fenestration product performance data used in compliance calculations must be provided through the NFRC rating program and must be labeled by the manufacturer with the rated U-factor, SHGC, and VT in accordance with §10-111 procedures.

Estimating the rate of heat transfer through a fenestration product is complicated by the variety of frame configurations for operable windows, the different combinations of materials used for sashes and frames, and the difference in sizes available in various applications. The NFRC rating system makes the differences uniform, so that an entire fenestration product line is assumed to have only one typical size. The NFRC-rated U-factor may be obtained from the directory of certified fenestration products, directly from a manufacturer's listing in product literature, or from the product label.

U-factor and solar heat gain (SHGC) are factors that affect the energy performance of a window. There is no minimum requirement for visual transmittance (VT) for low-rise residential buildings but is used for informational purposes. Product labels that clearly state these energy performance ratings help consumers compare the energy efficiency of window and glazed door products of different brands and manufacturers.

There are two types of labels that may be used to meet the requirements in the Energy Code: (1) an NFRC-certified product label or a default label. Manufactured products will need to have both an NFRC temporary label listing certified performance values and a permanent label with information that can be used to trace the product certification file and show that the manufacturer has certified the product per one of the testing methods described in Table 3-2. See the Certified Product Labels section for more information. (2) Default U-factors and SHGC are used when the manufacturer has not certified the product through the NFRC and for site-built fenestration. The temporary default label shall meet the requirements per §10-111. See the Default Label section for more information.

3.3.2.2 Certified Product Labels: Temporary and Permanent

1. Temporary Label for NFRC Certified Manufactured Fenestration Products

The Energy Code requires that manufactured fenestration have both temporary and permanent labels. The temporary label shows the U-factor and SHGC for each rated window unit. The label must also show that the product meets the air infiltration criteria of §110.6(a)1. The temporary label must not be removed before inspection by the enforcement agency.

Figure 3-2: Sample Temporary NFRC Label

 National Fenestration Rating Council® CERTIFIED	World's Best Window Co. Millennium 2000+ Vinyl-Clad Wood Frame Double Glazing • Argon Fill • Low E Product Type: Vertical Slider
ENERGY PERFORMANCE RATINGS	
U-Factor (U.S./I-P) 0.30	Solar Heat Gain Coefficient 0.30
ADDITIONAL PERFORMANCE RATINGS	
Visible Transmittance 0.51	Air Leakage (U.S./I-P) 0.2
<small>Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. www.nfrc.org</small>	

Source: National Fenestration Rating Council

2. National Fenestration Rating Council (NFRC) Permanent Label

The permanent label must, at a minimum, identify the certifying organization and have an ID number or code to allow tracking back to the original information on file with the certifying organization, NFRC. The permanent label can be inscribed on the spacer, etched on the glass, engraved on the frame, or otherwise located so as not to affect aesthetics.

3.3.2.3 Default Label: Temporary

The manufacturer can choose to use the Energy Code default values from Table 110.6-A for U-factors and Table 110.6-B for SHGC. The product shall meet the air infiltration requirements of §110.6(a)1, U-factor criteria of §110.6(a)2, and SHGC criteria of §110.6(a)3 in the Energy Code. The manufacturer must attach a temporary label meeting the following specific requirements. (Permanent etching labels are not required.)

There is no template for the default temporary label. It must be clearly visible and large enough for the enforcement agency field inspectors to read easily. It must include all information required by the Energy Code. The minimum suggested label size is 4 in. by 4

in., and the label must have the following words at the bottom of the label as noted in Figure 3-3:

"Product meets the air infiltration requirements of §110.6(a)1, U-factor criteria of §110.6(a)2, SHGC criteria of §110.6(a)3 and VT criteria of §110.6(a)4 of the 2022 California Building Energy Efficiency Standards for Residential and Nonresidential Buildings."

The manufacturer ensures the U-factor and SHGC default values are large enough to be readable from four feet away. The manufacturer ensures the appropriate boxes are checked and indicated on the default label.

Figure 3-3: Sample of Default Temporary Label

2022 California Energy Commission Default Label		
XYZ Manufacturing Co.		
Key Features:	<input type="checkbox"/> Doors	<input type="checkbox"/> Double-Pane
	<input type="checkbox"/> Skylight	<input type="checkbox"/> Glass Block
Frame Type:	Product Type:	Product Glazing Type:
<input type="checkbox"/> Metal	<input type="checkbox"/> Operable	<input type="checkbox"/> Clear
<input type="checkbox"/> Non-Metal	<input type="checkbox"/> Fixed	<input type="checkbox"/> Tinted
<input type="checkbox"/> Metal, Thermal Break	<input type="checkbox"/> Greenhouse/Garden Window	<input type="checkbox"/> Single-Pane
<input type="checkbox"/> Air space 7/16 in. or greater	-----	To calculate VT see NA6
<input type="checkbox"/> With built-in curb		
<input type="checkbox"/> Meets Thermal-Break Default Criteria		
California Energy Commission Default U-factor =	California Energy Commission Default SHGC =	California Energy Commission Calculated VT =
Products meets the air infiltration requirements of §110.6(a)1, U-factor criteria of §110.6(a)2, SHGC criteria of §110.6(a)3 and VT criteria of §110.6(a)4 of the 2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.		

Source: California Energy Commission

Note for Building Inspectors: At the field inspection, the field inspector verifies that the fenestration U-factor and SHGC values meet the energy compliance values by checking the label sticker on the product.

If no labels are available on site for verification, the field inspector should not allow any further installation of fenestration until proof of efficiency (label) is produced. In cases when proof is not met, the field inspector should not allow construction until the designer or builder can produce such labels.

Manufactured Products. Product must be rated by the National Fenestration Rating Council (NFRC) and be listed in NFRC's Certified Product Directory. The test procedure for U-factor is NFRC 100, and for SHGC and VT is NFRC 200 and NFRC

202, or ASTM E972 for translucent panels, and NFRC 203 for tubular daylighting devices (TDDs) and for certain types of other skylights.

When fenestration is not rated by the NFRC, the values found in Energy Commission Default Tables 110.6-A and 110.6-B in the Energy Code must be used. For example, a single-pane, operable, metal-framed fenestration product has a default U-factor of 1.28. To get credit for high-performance window features such as low-emissivity (low-e) coatings and thermal break frames, the window manufacturer must have the window tested, labeled, and certified according to NFRC procedures. When the Energy Code default values are used, they must be documented on a temporary default label (Figure 3-3).

- **Site-Built Products.** For special cases in single family construction in which site-built products are installed, the site-built products shall be treated the same as manufactured products. U-factor and SHGC values must come from NFRC ratings or from the default Table 110.6-A and Table 110.6-B of the Energy Code. Alternatively, calculation procedures in Reference Appendices, Nonresidential Appendix NA6 for nonrated site-built fenestration may be used if the area of the site-built fenestration in a dwelling is less than 250 ft² or 5 percent of the conditioned floor area, whichever is larger.
- **Field-Fabricated Products.** Field-fabricated fenestration must always use the Energy Commission default U-factors from Table 110.6-A and SHGC values from Table 110.6-B of the Energy Code.

Example 3-1: Labels When Using CEC Default Values

Question: When windows are labeled with a default value, are there any special requirements that apply to the label?

Answer: All windows must meet the mandatory requirements in §110.6 and §110.7, unless exempted. These criteria apply to fenestration products labeled with default values:

The administrative regulations (§10-111) require that the words “CEC Default U-factor” and “CEC Default SHGC” appear on the temporary label before the U-factor or SHGC (not in a footnote).

The U-factor and SHGC for the specific product must be listed. If multiple values are listed on the label, the manufacturer must identify the appropriate value for the labeled product. Marking the correct value must be done in one of the following ways:

1. Circle the correct U-factor and SHGC (permanent ink).
 2. Black out all values except the correct U-factor and SHGC (permanent ink).
 3. Make a hole punch next to the appropriate values.
-

3.3.3 U-Factor and SHGC Ratings §110.6(a), Table 110.6-A, Table 110.6-B

3.3.3.1 Determining U-Factor and SHGC

The Energy Code requires that U-factor and solar heat gain coefficient (SHGC) be calculated using standardized procedures to ensure that the thermal performance or efficiency data for fenestration products is accurate. The data provided by different manufacturers within each fenestration type (i.e., windows, doors, skylights, TDDs) can easily be compared to others within that type and can be verified independently.

Acceptable methods of determining U-factor and SHGC are shown in Table 3-2.

Table 3-2: Methods for Determining U-Factor and SHGC

U-Factor/SHGC Determination Method	Manufactured Windows and Doors	Manufactured Skylights	Site-Built Fenestration (Vertical & Skylight)	Field-Fabricated Fenestration	Glass Block
NFRC-100 (U-Factor) NFRC-200 (SHGC)	✓	✓	✓	N/A	N/A
Energy Code Default Table 110.6-A (U-Factor) Table 110.6-B (SHGC)	✓	✓	✓	✓	✓
NFRC's Component Modeling Approach (CMA) ¹	N/A	N/A	N/A	N/A	N/A
NA6 ²	N/A	N/A	✓	N/A	N/A

1. The NFRC CMA method is limited to nonresidential and is not currently approved for residential use.
2. The Alternative Default U-factors and SHGCs from Reference Appendices, Nonresidential Appendix NA6 may be used only for total site-built vertical fenestration plus skylights up to 250 ft² or 5% of the conditioned floor area, whichever is larger. Residential area allowances are defined in NA6.1(b).

Source: California Energy Commission

Note for Architects/Designers: When the alternative procedure from NA6 for unrated site-built fenestration is used in a residential application, it may not meet the prescriptive values as required by Table 150.1-A, even if area-weighted averaging is implemented. In this case, it would be necessary to use the performance approach to meet energy compliance.

Example 3-2: Multiple Window Types in a Project

Question: My new home will have a combination of window types, including fixed, operable, wood, metal, and so forth, some of which are field-fabricated. What are the options for showing compliance with the Energy Code?

Answer: All windows must meet the mandatory requirements of §110.6 and §110.7 and the mandatory maximum area-weighted average U-factor of 0.45 from §150.0(q), unless exempted. For field-fabricated windows, you must select U-factors and SHGC values from the default tables (Table 110.6-A and Table 110.6-B of the Energy Code). Windows that are not field-fabricated must be labeled with NFRC-certified or default efficiencies. Few fenestration products in the default tables meet the mandatory maximum U-factor of 0.45 on their own.

If the area-weighted average U-factors or SHGC values do not comply with the prescriptive requirements, the performance method must be used. To simplify data entry into the compliance software, you may choose the U-factor from Table 110.6-A of the Energy Code that is the highest of any of the windows planned to be installed and use this for all windows for compliance. However, you must use the appropriate SHGC from Table 110.6-B for each window type being installed.

Example 3-3: Glass Block

Question 1: Which U-factor is used for an operable metal-framed glass block?

Answer 1: For glass block, use the U-factor from Table 110.6-A of the Energy Code for the frame type in which the glass blocks are installed and for the fenestration product type. The U-factor for operable metal-framed glass block from Table 110.6-A is 0.87.

Question 2: Which SHGC is used for clear glass block, and can it be used for tinted glass block?

Answer 2: Use the default SHGC values from Table 110.6-B, depending upon whether the glass block has a metal or nonmetal frame and whether it is operable or fixed. The default SHGC table does not include tinted glass block, so use the clear glass block SHGC as the default for both clear and tinted glass block.

Question 3: Does it need a label?

Answer 3: Glass block is considered a field-fabricated product and may be installed only if compliance is demonstrated on the compliance documents.

Example 3-4: Sunrooms

Question: Is there a default U-factor for the glass in sunrooms?

Answer: If the sunroom is part of the conditioned floor area, then yes. For the horizontal or sloped portions of the sunroom glazing, use the U-factor for skylights. For the vertical portions, use the U-factors for fixed windows, operable windows, or doors, as appropriate. As a simple alternative, the manufacturer may label the entire sunroom with the highest U-factor of any of the fenestration types within the assembly.

Example 3-5: Glazed Doors

Question 1: How are exterior glazed doors treated in compliance documentation for U-factor and SHGC?

Answer 1: All doors with glass area greater than or equal to 25 percent of the door area, which includes French doors, are defined as fenestration products and are covered by the NFRC Rating and Certification Program. The U-factor and SHGC for doors with 25 percent or more glass area may be determined in one of two ways:

1. Use the NFRC rated and labeled values.
2. Refer to Table 110.6-A and 110.6-B of the Energy Code. The values are based upon glazing and framing type.

In special cases where site-built fenestration is being installed in a residential application, the site-built windows and glazed doors can use an alternative method to calculate the U-factor and the SHGC by using the manufacturer's center-of-glass values (COG). The COG values are calculated in accordance with Reference Appendices, Nonresidential Appendix NA6. To use this calculation, the maximum allowed site-built fenestration is 250 ft² or 5% of the conditioned floor area, whichever is larger.

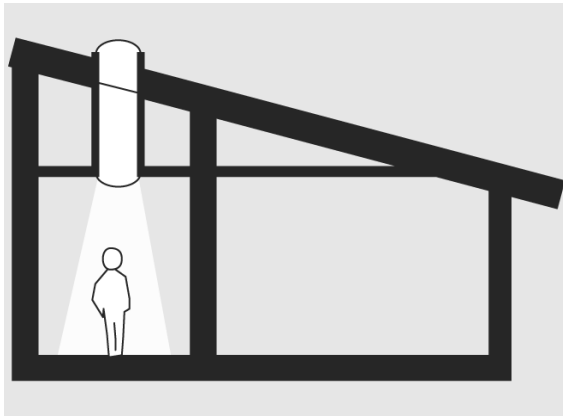
Question 2: How can I determine a U-factor and SHGC for doors when less than 25 percent of the door area is glass?

Answer 2: Doors with less than 25 percent glass area are treated as opaque exterior doors. For prescriptive or performance approaches, only the U-factor is used for this product type. Use one of the following options for U-factor of the door:

1. The NFRC label if one is available
 2. The default values from Table JA4.5.1 of the Reference Appendices
-

Example 3-6: Tubular Daylighting Device with Single-Pane Diffuser

Question: A tubular daylighting device (TDD) will be used to get daylight into a house. The skylight has a clear plastic dome exterior to the roof, a single-pane ¼-inch (6 mm)-thick acrylic diffuser mounted at the ceiling, and a metal tube connecting the two. How are U-factor and SHGC determined for the performance approach to comply with the Energy Code, if U_c is 1.20 and $SHGC_c$ is 0.85?



Answer: There are three methods available for determining the U-factor for tubular daylighting devices (TDD):

1. Use the NFRC label if the product has been tested and certified under NFRC procedures. This requires a label that states: "Manufacturer stipulates that this rating was determined in accordance with applicable NFRC procedures NFRC 100," followed by the U-factor.
2. Use the default U-factor from Table 110.6-A of the Energy Code. This tubular product would be considered a metal frame, fixed, single-pane skylight resulting in a U-factor of 1.19, which must appear on a label preceded by the words "CEC Default U-factor." (A tubular daylighting device would have to have two panes of glazing with an air space of less than 2 inches [50 mm] between them at the plane of the ceiling insulation for it to be considered double-pane.)
3. Determine the U-factor from Reference Appendices, Nonresidential Appendix NA6, Equation NA6-1. The U-factor for this tubular daylighting device would be based on metal with no curb (Table NA6-5). The U-factor for this skylight, using Equation NA6-1, is 1.25, where $U_t = (0.195 + (0.882 \times 1.20))$. This must appear on a label stated as "CEC Default U-factor 1.25."

There also are three methods available for determining SHGC for tubular daylighting devices (TDD):

1. Use the NFRC label if the skylight has been tested and certified under NFRC procedures and requires a label that states: "Manufacturer stipulates that this rating was determined in accordance with applicable NFRC procedures."
2. Use the default table SHGC in Table 110.6-B of the Energy Code. This tubular daylight device would be considered a metal-frame, fixed, clear, single-pane skylight resulting in an SHGC of 0.83, which must appear on a label stated as "CEC Default SHGC 0.83."
3. Determine the SHGC from Reference Appendices, Nonresidential Appendix NA6, Equation NA6-2. The SHGC for this skylight using Equation NA6-2 is 0.81, where $SHGC_t = (0.08 + (0.86 \times 0.85))$. This must appear on a label stated as "CEC Default SHGC 0.81."

Example 3-7: Tubular Daylighting Device with Dual-Pane Diffuser

Question: How are the U-factor and the SHGC determined if the tubular daylighting device (TDD) in the previous example has a dual-pane diffuser (instead of single-pane) mounted at the ceiling?

Answer: The procedure would be the same as Example 3-6, except that the double-pane U-factor and SHGC values from Tables 110.6-A and 110.6-B of the Energy Code would be used instead of single-pane values. Up to 3 ft² of tubular daylighting device with a dual-pane diffuser is assumed to have the prescriptive U-factor and SHGC from Table 150.1-A for compliance calculations (Exception 1 to §150.1[c]3A).

3.3.4 Air Leakage §110.6(a)1, §110.7

- Air leakage is a measurement of heat loss and gain by infiltration and exfiltration through cracks in the window assembly, which can affect occupant comfort. The lower the air leakage, the lower the amount of air that will pass through cracks in the window assembly.
 - A. **Manufactured Products.** Must be tested and certified to leak no more than 0.3 cubic feet per minute (cfm) per ft² of the window area. This mandatory requirement applies to all manufactured windows that are installed in newly constructed residential (including high-rise) buildings or newly installed in existing buildings. To determine air leakage, the standard test procedure requires manufacturers to use either NFRC 400 or ASTM E283 at a pressure differential of 75 Pascal (or 1.57 pounds/ft²).
 - B. **Site-Built Products.** There are no specific air leakage requirements for site-built fenestration products, but the Energy Code requires limiting air leakage by weatherstripping and caulking.
 - C. **Field-Fabricated Products.** No air leakage testing is required for field-fabricated fenestration products; however, the Energy Code still requires limiting air leakage by weatherstripping and caulking.
 - D. **Exterior Doors.** Exterior doors, which includes pet doors, must meet the following requirements:
 1. Manufactured exterior doors must be certified as meeting an air leakage rate of 0.3 cfm/ft² of door area at a pressure differential of 75 Pascal, which is the same as windows.
 2. Field-fabricated exterior doors must comply with the requirements of §110.6, as described by "Other Openings." For example, these must be caulked and weather stripped.
 3. Any door with a surface area greater than or equal to 25 percent glass is considered a glazed door and must comply with the mandatory and applicable prescriptive and performance requirements of §150.0, §150.1, and §150.2.

4. For any door with a surface area less than 25 percent glass, the area may be exempt in accordance with one of the exceptions of §150.0, §150.1, and §150.2.

Example 3-8: Which Fenestration Products Must Be Tested and Certified for Air Leakage?

Question: As a manufacturer of fenestration products, I place a temporary label with the air infiltration rates on my products. Can you clarify which products must be tested and certified?

Answer: Each product line must be tested and certified for air infiltration rates. Features such as weather seal, frame design, operator type, and direction of operation affect air leakage. Every product must have a temporary label certifying that the air infiltration requirements are met. This temporary label may be combined with the temporary U-factor, SHGC, and VT label.

Example 3-9: Infiltration Requirements for Custom Windows

Question: Is a custom window “field-fabricated” for meeting air infiltration requirements?

Answer: No. Most custom windows are manufactured and delivered to the site either completely assembled or “knocked down,” which means they are a manufactured product. A window is considered field-fabricated when the windows are assembled at the building site from the various elements that are not sold together as a fenestration product (such as glazing, framing, and weatherstripping). Field-fabricated does not include site-assembled frame components that were manufactured elsewhere with the intention of being assembled on site (such as knocked-down products, sunspace kits, and curtain walls).

Example 3-10: Pet Doors to the Exterior

Question: How is a pet door installed in an exterior wall accounted for in a newly constructed residential building design?

Answer: Pet doors must meet all exterior door requirements. U-factor must be determined by an NFRC accredited testing lab using NFRC 100 U-factor requirements; otherwise, nonrated pet doors will assume no more than the maximum U-factor of 0.99 based on a nonmetal single-pane door U-factor. (See Table 110.6-A of the Energy Code.) The rated pet door shall not exceed 0.3 cfm/ft² air leakage when tested using ASTM E283. The performance compliance approach must be used when a pet door is installed.

3.3.5 Prescriptive Requirements §150.1(c)3, §150.1(c)4, §150.1(c)5, and Table 150.1-A

Fenestration

Prescriptive requirements described in this chapter typically refer to Table 150.1-A. The maximum fenestration U-factor required prescriptively for all climate zones is 0.30, and the maximum SHGC is 0.23 for residences in climate zones 2, 4, and 6 through 15. Homes constructed in climate zones 1, 3, 5, and 16 have no SHGC requirements.

The requirements apply to fenestration products without consideration of insect screens or interior shading devices. With some exceptions, some fenestration products may exceed the prescriptive requirement as long as the U-factor and SHGC of windows, glazed doors, and skylights can be area weight-averaged together to meet the prescriptive requirement using the CF1R-ENV-02-E compliance document in Appendix A of this manual.

Opaque Doors

An *opaque door* is an installed swinging door separating conditioned space from outside or adjacent unconditioned space with less than 25 percent glazed area. A door that has 25 percent or more glazed area is considered a glazed door and is treated like a fenestration product (Section 3.5.8).

Opaque doors are prescriptively required to have an area-weighted average U-factor no greater than U-0.20, per Table 150.1-A. Swinging doors between the garage and conditioned space that are required to have fire protection are exempt from the prescriptive requirement. The U-factor must be rated in accordance with NFRC 100, or the applicable default U-factor defined in Reference Appendices, Joint Appendix Table JA4.5.1 must be used.

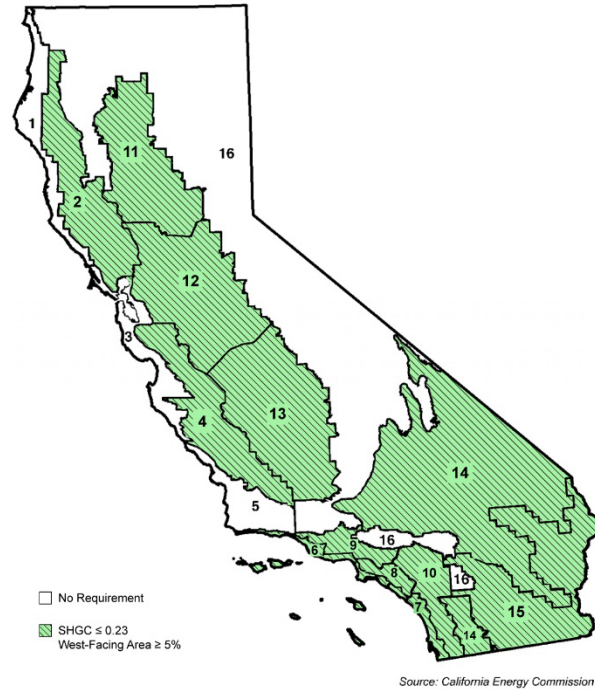
Note for Building Inspectors: At the field inspection, the field inspector verifies that the door U-factor meets the energy compliance values by checking the NFRC label sticker on the product. When manufacturers do not rate the thermal efficiencies by NFRC procedures, the Energy Commission default values must be used and documented on a temporary default label (Figure 3-3).

Table 3-3: Maximum U-Factors, SHGC, and Fenestration Area by Climate Zone in the Prescriptive Package

Climate Zone	1, 3, 5, 16	2,4,6-15
Maximum Fenestration U-Factor	0.30	0.30
Maximum Fenestration SHGC	NR	0.23
Maximum Fenestration Area	20%	20%
Maximum West-Facing Fenestration Area	NR	5%
Maximum Opaque Door U-Factor	0.20	0.20

Source: California Energy Commission

Figure 3-3-4: Prescriptive Package, SHGC, and West-Facing Area Criteria by Climate Zone



Source: California Energy Commission

3.3.5.1 Fenestration and Opaque Door Prescriptive and Mandatory Exceptions

A. Glazed Doors

Any door that is more than 25 percent or greater glass is considered a glazed door and must comply with the mandatory requirements and other requirements applicable to a fenestration product. Up to 3 ft² of glass in a door is exempt from the U-factor and SHGC requirements (or can be considered equivalent to the prescriptive package values). The U-factor and SHGC shall be based on either the NFRC values for the entire door, including glass area, or use default values in Table 110.6-A for the U-factor and Table 110.6-B for the SGHC. If the door has less than 25 percent glazing, the glazing portion of the door is ignored in the prescriptive approach.

B. Tubular Daylighting Device (TDD)

In each dwelling unit, up to 3 ft² of tubular daylighting devices area with dual-pane diffusers at the ceiling are exempt from the prescriptive U-factor and SHGC requirements, where the TDD area is included in the maximum of 20 percent fenestration area. However, the U-factor shall not exceed a maximum of 0.45. See §150.0(q) and Exception 1 of §150.1(c)3A.

C. Opaque Doors

- Opaque doors between the garage and conditioned space that are required to have fire protection are not required to meet the prescriptive U-factor requirement of 0.20. See Exception to §150.1(c)5.

D. Skylights

- Each new dwelling unit may have up to 16 ft² of skylight area. The total area of skylights is included in the maximum of 20 percent fenestration area and must meet a maximum 0.55 U-factor and a maximum SHGC of 0.30. See Exception 2 of §150.1(c)3A.

Aside from the specific exceptions to the fenestration prescriptive requirements, the area weight-averaged U-factor and SHGC must not exceed the 0.55 U-factor and cannot be greater than the 0.30 SHGC when large numbers of skylights are used for prescriptive compliance. Alternatively, the performance approach may be used to meet energy compliance.

E. Dynamic Glazing

If a dwelling unit includes a type of dynamic glazing that is electrochromatic, chromogenic, or an integrated shading device and the glazing is automatically controlled, use the lowest U-factor and lowest SHGC to determine compliance with prescriptive package fenestration requirements. Since this type of product has compliance ratings that vary, it cannot be weight averaged with nonchromogenic products as per Exception 3 of §150.1(c)3A.

F. Site-Built Fenestration

When a dwelling unit contains a combination of manufactured and site-built fenestration, only the site-built fenestration values can be determined by using Reference Appendices, Nonresidential Appendix NA6. All fenestration, including site-built, can default to Table 110.6-A and Table 110.6-B.

G. Maximum Area

The prescriptive requirements limit total glass area to a maximum of 20 percent of the conditioned floor area in all climate zones.

- **Note:** There are exceptions to the prescriptive requirements for alterations in §150.2(b)1A that allow additional glass area beyond the 20 percent limitation, including west-facing glass. See Chapter 9 for more information on alterations.

H. Greenhouse Windows/Garden Windows

- Compared to other fenestration products, the NFRC-rated U-factor for greenhouse windows are comparatively high. Section 150.0(q) includes an exception from the U-factor requirement for dual-glazed greenhouse or garden windows that total up to 30 ft² of fenestration area.

3.3.5.2 Prescriptive Credit for Exterior Shading Devices §150.1(c)4

The prescriptive requirements require fenestration products with a SHGC of 0.23 or lower in climate zones 2, 4, and 6 through 15. However, a fenestration product with an SHGC greater than 0.23 may be used with the prescriptive requirements if a

qualifying exterior shading device is used and the combined area-weighted average complies with the prescriptive requirements. Exterior shading devices and associated SHGC values are shown in Table 3-4. These include woven sunscreens as well as perforated metal sunscreens. As shown in the table, these devices transmit between 13 percent and 30 percent of the sun that strikes them.

Table 3-4: Exterior Shades and Solar Heat Gain Coefficients

Exterior Shading Device	SHGC*
Standard Bug (insect) Screen (default for windows)	0.76
Exterior Sunscreens with Weave 53 x 16/inch	0.30
Louvered Sunscreens w/Louvers as Wide as Window Openings	0.27
Low-Sun-Angle Louvered Sunscreen	0.13
Vertical Roller Shades or Retractable/Drop Arm/Combination/Marquisolette and Operable Awnings	0.13
Roll Down Blinds or Slats	0.13
None (for skylights only)	1.00

* Reference glass values assume single-pane clear glass and metal framing 1/8-inch double-strength (DSS) glass. Use CF1R-ENV-03 worksheet for calculation.

Source: California Energy Commission

When exterior overhangs are used, the SHGC requirements of the prescriptive package may be met if the calculated combination of the overhang and fenestration SHGC efficiency is equal or lower than 0.23.

For credit, exterior shading devices must be permanently attached as opposed to being attached using clips, hooks, latches, snaps, or ties. Exterior shading devices on windows or skylights that are prohibited by life-safety codes from being permanently attached for emergency egress reasons are exempt from this requirement.

Notes for Plans Examiners: Compliance document CF1R-ENV-03 is used to calculate the combined SHGC of windows and exterior shading devices. When exterior shades are required for compliance, they must be listed on the CF1R and be documented on the plans.

The SHGC of the window in combination with an exterior device is given by the following:

$$\text{Equation 3-1: } SHGC_{\text{combined}} = (0.2875 \times SHGC_{\text{max}} + 0.75) \times SHGC_{\text{min}}$$

All operable windows and skylights are assumed to have an insect screen as the default condition against which other window and exterior shading device combinations are compared. The standard case is a window with an SHGC of 0.23

and an insect screen with an SHGC of 0.76. For this default case, the SHGC of the window is the $SHGC_{min}$, and the SHGC of the exterior sunscreen is $SHGC_{max}$. Working through the math on the CF1R-ENV-03 form, $SHGC_{combined}$ is 0.23. This means that any combination of window SHGC and exterior SHGC that results in a $SHGC_{combined}$ of 0.23 or less complies with the prescriptive requirements.

Most of the shading devices (other than the default insect screen) have an SHGC of 0.30 or lower. Combining this with the SHGC of any window may result in a combined SHGC that is equal to or lower than the prescriptive criterion of 0.23. This method of combining the SHGC of the window with the SHGC of the exterior shading device can also be used in the whole-building performance approach.

3.3.6 Fenestration in the Performance Approach §150.1(b)

While the prescriptive requirements and mandatory requirements establish a minimum level of building energy performance, opportunities to exceed the requirements of the Energy Code are considerable. More information is included in the Performance Compliance section (Chapter 8).

Note for Architects/Designers: Options that are recognized for credit through the performance method are called *compliance options*. Most require using the performance approach, but a few exterior shading devices and south-facing overhangs may be used to comply when using the prescriptive approach.

3.3.6.1 Fenestration Area and Orientation

The performance approach includes consideration of the fenestration area and orientation, which can have a big effect on energy use. Compliance is determined by comparing the proposed fenestration to the standard design fenestration.

For buildings with glazing areas less than or equal to 20 percent of the conditioned floor area (CFA), the standard design fenestration for a newly constructed building is modeled with the same glazing area as the proposed home with one-quarter of the window area on the north, east, south, and west orientations. For buildings with more than 20 percent of the CFA, the standard design is limited to 20 percent glass area.

Because of the effects of orientation and the fenestration product performance levels and other building features like overhangs, judging the particular area, orientation, and performance level is a compliance credit or penalty and can be difficult to determine without performance approach calculations.

3.3.6.2 Improved Fenestration Performance

The fenestration weighted average U-factor in the standard design for newly constructed buildings is 0.30 in all climate zones. Choosing high-performance fenestration that performs better than the prescriptive requirements level can earn significant credit through the performance method. For example, in warmer climates (e.g., climate zones 8-15), choosing a window with an SHGC lower than 0.23 will

reduce the cooling loads compared to the standard design. In colder climates (e.g., climates zones 1, 3, 5 and 16) where there are no prescriptive SHGC requirements, choosing a window with an SHGC of 0.35 or lower will inadvertently increase the heating loads compared to the standard design.

The magnitude of the effect will vary by climate zone. In mild coastal climates, the benefit from reducing fenestration U-factor will be smaller than in cold, mountain climates. Several factors affect window performance. For fenestration with NFRC ratings, the following performance features are accounted for in the U-factor and SHGC ratings:

1. Frame materials, design, and configuration (including cross-sectional characteristics). Fenestration can be framed in many materials. The most common include wood, aluminum, vinyl, fiberglass, or composites of these materials. Frames made of low-conductance materials like wood, vinyl, and fiberglass are better insulators than metal. Some aluminum-framed units have thermal breaks that reduce the conductive heat transfer through the framing element compared with similar units having no such conductive thermal break.
2. Number of panes of glazing, low-emissivity coatings, tints, fill gases, cavity dimensions, and spacer construction. Windows compliant with the prescriptive requirements are likely to have at least double-glazing with a low-emissivity coating and argon gas fill with an improved spacer. The choice of low-emissivity coating is particularly important as cooling climates will generally benefit from a low SHGC coating, while heating climates may benefit from a high SHGC coating. There are many ways to improve performance beyond the prescriptive levels. Adding glazing layers such as triple glazing and low-emissivity coatings such as those facing the conditioned space are two likely improvements.
3. Dynamic glazing with appropriate controls may also offer opportunities for improving performance.

3.3.6.3 Fixed Permanent Shading Devices

Shading of windows is also an important compliance option. Overhangs or sidefins that are attached to the building or shading from the building itself are compliance options for which credit is offered through the performance approach. However, no credit is offered for shading from trees, adjacent buildings, or terrain.

The ideal overhang is one that provides shade during the months when the building is likely to be in cooling mode and allows direct solar gains in the heating months. During the summer, the sun is high as it passes over the south side, while in the winter it is low, enabling solar radiation to pass beneath the overhang. Windows that face south can be effectively shaded by overhangs positioned above the window. Due to the potential effectiveness of south-facing overhangs, a prescriptive compliance option is offered. See Section 3.3.5.2 for details.

Shading is more challenging on the east and west sides of the house. When the sun strikes these façades, it is low in the sky, making overhangs ineffective. Vertical fins can be effective, but they degrade the quality of the view from the window and limit the natural light that can enter. In cooling-dominated climates, the best approach is to minimize windows that face east and west. Landscaping features can be considered to increase comfort and energy performance of the building but cannot be used for compliance credit.

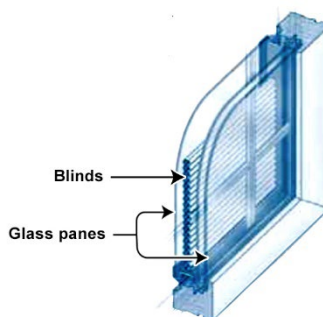
3.3.6.4 Interior Shading Devices

There is no credit for interior aftermarket shading devices, although they can be effective in reducing solar gains and should be considered by homeowners. These added interior shades are in the category of home furnishings and not a feature of the house that is provided by the builder or fenestration manufacturer. Draperies, interior blinds, interior shades, and other interior devices are not credited toward energy compliance. A default standard bug screen is still considered in performance calculations, so that estimates of energy use are more realistic and tradeoffs against other requirements are more equitable.

3.3.6.5 Dynamic Glazing

Dynamic glazing products are either integrated shading systems or electrochromatic devices and are considered a fenestration product.

Figure 3-5: Diagram of Integrated Shading System



Source: NFRC Dynamic Glazing Products Fact Sheet

Integrated Shading Systems. These systems include blinds positioned between glass panes that can be opened and closed using automatic controls, See Figure 3-5.

The labels for integrated shading systems will reflect the endpoints of the product performance for U-factor and SHGC (Figure 3-6). The unique rating “variable arrow” identifier helps consumers understand the “dynamics” of the product and allows comparison with other similar dynamic fenestration products.

If the fenestration product can operate at intermediate states, a dual directional arrow (\leftrightarrow) with the word “Variable” will appear on the label. Some dynamic glazing can adjust to intermediate states, allowing for a performance level between the endpoints.

Figure 3-6: Example of Integrated Shading System NFRC Label

 World's Best Window Co. Millennium 2000+ Vinyl-Clad Wood Frame Double Glazing • Dynamic Glazing • Argon Fill • Low E Product Type: Vertical Slider	
ENERGY PERFORMANCE RATINGS	
U-Factor (U.S./I-P) 0.30 ↔ 0.40 <small>Off/Closed On/On</small>	Solar Heat Gain Coefficient 0.10 ↔ 0.50 <small>Off/Closed On/On</small>
ADDITIONAL PERFORMANCE RATINGS	
Visible Transmittance 0.03 ↔ 0.65 <small>Off/Closed On/On</small>	Air Leakage (U.S./I-P) 0.2
<small>Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. www.nfrc.org</small>	

In Figure 3-6, the low value rating is displayed to the left (in the closed or darker position), and the high value rating is displayed to the right (in the open or lighter position). This lets the consumer know at a glance the best and worst case performance of the product and the default performance level. To use the high-performance values for integrated shading systems, the product must have an NFRC Certified Label sticker. Otherwise, the default values from Tables 110.6-A and 110.6-B must be used.

Figure 3-7: Chromatic Glazing

Source: NFRC Dynamic Glazing Products Fact Sheet

- Chromatic Glazing.** One type of dynamic glazing product uses a chromatic type of glass that can change the performance properties, allowing occupants to control their environment manually or automatically by tinting or darkening a glass with the flip of a switch. Some fenestration products can change performance automatically with the use of an automatic control or environmental signals. These high-performance windows can reduce energy costs due to controlled daylighting and unwanted heat gain or heat loss.

A view of chromatic glazing in the open (off) and closed (on) position is shown in Figure 3-7. Best-rated performance values may be used for compliance with an NFRC Certified Label sticker and when automatic controls are installed.

- If the window includes either an NFRC label or automatic controls, but not both, then default to Table 150.1-A maximum U-factor of 0.30 and maximum SHGC of 0.23.

Source: Sage
Electrochromics

- If neither an NFRC label nor automatic controls are included, then the default values from Tables 110.6-A and 110.6-B of the Energy Code must be used.

3.3.6.6 Window Films §150.1(b)

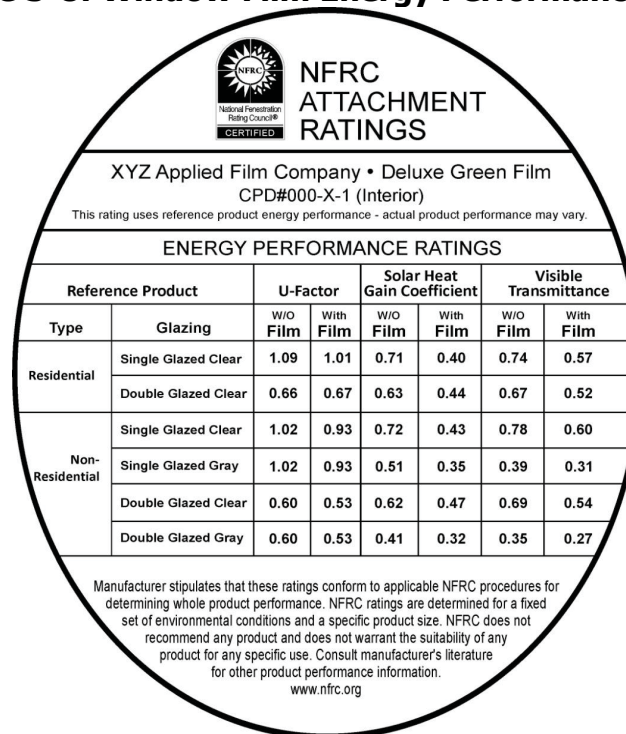
Window films are polyester films that offer high clarity and can be pretreated to accept different types of coatings. There are three basic categories of window films:

- **Clear** (nonreflective) films are used as security film to reduce ultraviolet (UV) light, which contributes greatly to fading. They are not commonly used for solar control or energy savings.
- **Tinted or dyed** (nonreflective) films reduce both heat and light transmission, mostly through increased absorbance, and can be used in applications where the desired primary benefit is glare control, with energy savings being secondary.
- **Metalized** (reflective) film can be metalized through vacuum coating, sputtering, or reactive deposition and may be clear or colored. Metalized films are preferred for energy savings applications because they reduce transmission primarily through reflectance and are manufactured to reflect heat more than visible light through various combinations of metals.

To receive window film compliance credit, the following must be met:

- The performance approach must be used to meet energy compliance.
- NFRC Window Film Energy Performance Label (Figure 3-8) is required for each different film applied. If there is no NFRC label, the default values from Tables 110.6-A and Table 110.6-B of the Energy Code must be used.
- Window films must have at least a 15-year manufacturer warranty.

Figure 3-8 shows an example of a NFRC Attachment Ratings Label, which helps identify the energy performance of window films.

Figure 3-8: Window Film Energy Performance Label

Source: NFRC Applied Film Products Fact Sheet

3.3.6.7 Bay Windows §150.1(b)

Bay windows are a special compliance case. Bay windows may have a unit NFRC rating (that is, the rating covers both the window and all opaque areas of the bay window), an NFRC rating for the window only, or no NFRC rating. Nonrated bay windows may or may not have factory-installed insulation.

A. NFRC Rated

For bay windows that come with an NFRC rating for the entire unit, compliance is determined based on the rough opening area of the entire unit, applying the NFRC U-factor and SHGC. If the unit U-factor and SHGC do not meet the package requirements or area-weighted average, the project must show compliance using the performance approach.

B. Nonrated

Bay windows with no rating for the entire unit (where there are multiple windows that make up the bay) and with factory-installed or field-installed insulation must comply accounting for the performance characteristics of each component separately.

- Opaque portions of bay windows including roofs and floors must be insulated to meet the wall insulation requirements for prescriptive compliance. The opaque portion must either meet the minimum insulation requirements of the prescriptive package for the applicable climate zone or be included in a weighted average U-factor calculation

of an overall opaque assembly that does meet the prescriptive requirements.

- For the windows, the U-factor and SHGC values may be determined either from an NFRC rating or by using default values in Tables 110.6-A and 110.6-B of the Energy Code. If the window U-factor and SHGC meet the package requirements, the bay window complies prescriptively (if overall building fenestration area meets prescriptive compliance requirements).
- If the bay window does not meet prescriptive requirements, the project must show compliance using the performance approach.

3.4 Opaque Envelope

This section of the building envelope chapter addresses the requirements for air leakage, roof products, radiant barriers, and vapor retarders in the building envelope. Fenestration, windows, glazed doors, and opaque doors are addressed in Section 3.3. Insulation is addressed in Section 3.5.

Table 3-5: Relevant Sections in the Energy Code

Newly Constructed and Additions ≥ 1,000 ft²	MANDATORY	PRESCRIPTIVE	PERFORMANCE
Air Leakage	§110.7	-	-
Roofing and Radiant Barriers	§10-113, §110.8(i) - §110.8(j)	§150.1(c)2, §150.1(c)11 Table 150.1-A	§150.1(a), §150.1(b)
Vapor Retarders	§150.0(g)	-	-

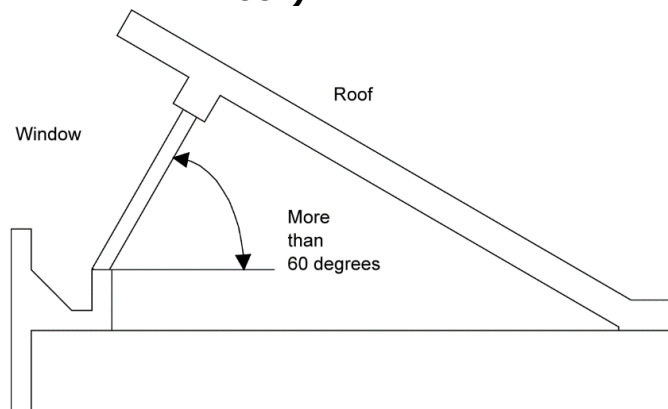
Source: California Energy Commission

3.4.1 Opaque Envelope Definitions

- Opaque elements of the building envelope significantly contribute to the related energy efficiency. Components of the building envelope include walls, floors, soffits, roofs, and ceilings. Envelope and other building components definitions are listed in §100.1(b) of the Energy Code and the Reference Appendices, Joint Appendix JA1.
 - The exterior partition** is an opaque, translucent, or transparent solid barrier that separates conditioned space from ambient air or unconditioned space.
 - The demising partition** is a wall, fenestration, floor, or ceiling that separates conditioned space from enclosed unconditioned space.

- C. **The conditioned space** is an enclosed space within a building that is either directly conditioned or indirectly conditioned.
- D. **Unconditioned space** is enclosed space within a building that is neither directly conditioned nor indirectly conditioned.
- E. **Plenum** is an air compartment or chamber, including uninhabited crawl space, areas above a ceiling or below a floor, or attic spaces, to which one or more ducts are connected and that forms part of either the supply-air, return-air, or exhaust air system, other than the occupied space being conditioned.
- F. **Attic** is an enclosed space directly below the roof deck and above the ceiling.
- G. **Sloping surfaces** are considered either a wall or a roof, depending on the slope. (See Figure 3-9.) If the surface has a slope of less than 60° from horizontal, it is considered a roof; a slope of 60° or more is a wall. This definition extends to fenestration products, including windows in walls and any skylight types in roofs.

Figure 3-9: Slope of a Wall or Window (Roof or Skylight Slope Is Less Than 60°)



Source: California Energy Commission

- H. **The exterior roof** is an exterior partition that has a slope less than 60 degrees from horizontal, that has conditioned space below, and that is not an exterior door or skylight.
- I. **The roof deck** is the surface that supports the roofing material. Typically made of plywood or OSB, it is supported by the roof framing members such as rafters or trusses.
- J. **Exterior floor/soffit** is a horizontal exterior partition, or a horizontal demising partition, under conditioned space.
- K. **Vapor retarder** or vapor barrier is a material or assembly designed to limit the amount of vapor moisture that passes through that material or assembly.

- L. **Roofing products** are the top layer of the roof that is exposed to the outside, which has properties including, but not limited to, solar reflectance, thermal emittance, and mass.
- M. **Cool roof** is a roofing material with high thermal emittance and high solar reflectance, or low thermal emittance and exceptionally high solar reflectance, as specified in Part 6, that reduces heat gain through the roof.
- N. **Solar reflectance** is the fraction of solar energy that is reflected by the roof surface.
- O. **Thermal emittance** is the fraction of thermal energy that is emitted from the roof surface.
- P. **A low-sloped roof** is a surface with a pitch less than 2:12 (less than 9.5 degrees from the horizon).
- Q. **A steep-sloped roof** is a surface with a pitch greater than or equal to 2:12 (9.5 degrees or greater from the horizontal).
- R. **Air leakage** is a measurement of heat loss and gain by infiltration and exfiltration through gaps and cracks in the envelope.
- S. **Infiltration** is the *unintentional* replacement of conditioned air with unconditioned air through leaks or cracks in the building envelope. It is a major component of heating and cooling loads. Infiltration can occur through holes and cracks in the building envelope and around doors and fenestration framing areas.

Reducing infiltration in the building envelope can result in significant energy savings, especially in climates with severe winter and summer conditions. It also can result in improved occupant comfort, reduced moisture intrusion, and fewer air pollutants.
- T. **Exfiltration** is uncontrolled outward air leakage from inside a building, including leakage through cracks, joints, and intersections, around windows and doors, and through any other exterior partition or duct penetration.
- U. **Ventilation** is the *intentional* replacement of conditioned air with unconditioned air through open windows and skylights or mechanical systems.

3.4.2 Air Sealing and Air Leakage §110.7, §150.0

3.4.2.1 Joints and Other Openings §110.7

Air leakage through joints, penetrations, cracks, holes, openings around windows, doors, walls, roofs, and floors can result in higher energy use. The following openings in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed:

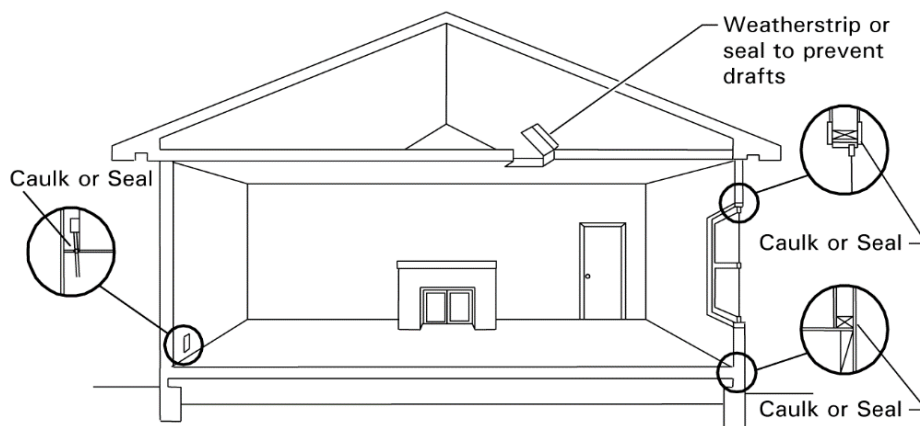
1. Exterior joints around window and door frames (including doors between the house and garage), between interior HVAC closets and conditioned space, between attic access and conditioned space, between wall sill plates and the floor, exterior panels, and all siding materials.
2. Openings for plumbing, electricity, and gas lines in exterior and interior walls, ceilings, and floors.
3. Openings in the attic floor, such as where ceiling panels meet interior walls, exterior walls, and masonry fireplaces.
4. Openings around exhaust ducts, such as those for clothes dryers.
5. All other such openings in the building envelope.

Figure 3-10: Air Sealing



Source: Sierra Building Science

Figure 3-11: Caulking and Weatherstripping



Source: California Energy Commission

Note for Contractors/Installers: Alternative strategies may be used to meet the mandatory caulking and sealing requirements for exterior walls.

These include, but are not limited to:

1. Stucco.
2. Caulking and taping all joints between wall components (for example, between slats in wood slat walls).
3. Building wraps.
4. Rigid wall insulation installed continuously on the exterior of the building with all joints taped, gasketed, or otherwise sealed.

3.4.2.2 Fireplaces, Decorative Gas Appliances, and Gas Logs §150.0(e)

The Energy Code has mandatory requirements to limit infiltration associated with fireplaces, decorative gas appliances, and gas logs. Reduced infiltration is a benefit when the fireplace is not operating (the majority of the time for most homes).

3.4.3 Roofing Products §10-113, §110.8(i), §150.1(c)11


In general, light-colored, high-reflectance surfaces reflect solar energy (visible light and invisible infrared and ultraviolet radiation) and stay cooler than darker surfaces that absorb the sun's energy and become heated. The Energy Code prescribes cool roof radiative properties for low-sloped and steep-sloped roofs. Low-sloped roofs receive more solar radiation than steep-sloped roofs in the summer when the sun is higher in the sky.

Roofing products installed to take compliance credit or meet the prescriptive requirements for reflectance and emittance shall be rated by the Cool Roof Rating Council (CRRC) and labeled appropriately by the roofing manufacturer for solar reflectance and thermal emittance. The solar reflectance and thermal emittance properties are rated and listed by the Cool Roof Rating Council at (www.coolroofs.org/).

3.4.3.1 Product Labels §10-113

Figure 3-12 shows a sample Cool Roof Rating Council product label. The label includes solar reflectance and thermal emittance values.

Figure 3-12: Sample CRRC Product Label and Information

	Solar Reflectance	Initial 0.00	Weathered Pending
	Thermal Emittance	0.00	Pending
	Rated Product ID Number		
	Licensed Seller ID Number		
Classification		Production Line	
<p>Cool Roof Rating Council ratings are determined for a fixed set of conditions, and may not be appropriate for determining seasonal energy performance. The actual effect of solar reflectance and thermal emittance on building performance may vary.</p> <p>Manufacturer of product stipulates that these ratings were determined in accordance with the applicable Cool Roof Rating Council procedures.</p>			

Source: Cool Roof Rating Council

Solar reflectance and thermal emittance are measured from 0 to 1; the higher the value, the "cooler" the roof. There are numerous roofing materials in a wide range of colors that have adequate cool roof properties. Reducing heat gains through the roof will reduce the cooling load of the home, resulting in reduced air-conditioned energy needed to maintain occupant comfort. High-emitting roof surfaces reject absorbed heat quickly (upward and out of the building) than roof surfaces with low-emitting properties.

Solar Reflectance (SR). There are three solar reflectance measurements:

1. Initial solar reflectance
2. Three-year aged solar reflectance
3. Accelerated aged solar reflectance

All requirements of the Energy Code are based on the three-year aged solar reflectance (SR). If the aged SR value is not available in the CRRC's Rated Product Directory, then the aged value shall be derived from the CRRC aged value equation (using the initial value for solar reflectance) or an accelerated process. Until the appropriate aged-rated value for the reflectance is posted in the directory, the equation below can be used to calculate the aged rated solar reflectance, or a new method of testing is used to find the accelerated solar reflectance.

Calculating Aged Solar Reflectance from Initial Reflectance

$$\text{Equation 3-1: Aged Reflectance}_{\text{calculated}} = (0.2 + \beta[\rho_{\text{initial}} - 0.2])$$

Where:

ρ_{initial} = Initial Reflectance listed in the CRRC Rated Product Directory

β = soiling resistance which is listed in Table 3-6

Table 3-6: Values of Soiling Resistance β by Product Type

PRODUCT TYPE	β
Field-applied coating	0.65
Other	0.70

Source: California Energy Commission

Thermal Emittance (TE). The Energy Code does not distinguish between initial and aged thermal emittance, meaning either value can be used to demonstrate compliance with the Energy Code.

Note for Contractors/installers: What is Solar Reflectance Index (SRI)?

An alternative to the aged solar reflectance and thermal emittance required values is to use the Solar Reflectance Index (SRI) to show compliance. A calculator has been produced to calculate the SRI by inputting the three-year aged solar reflectance and thermal emittance of the desired roofing material.

The calculator can be found at <http://www.energy.ca.gov/title24/2022standards>.

By using the SRI alternative, a cool roof may comply with a lower emittance, as long as the aged reflectance is higher, and vice versa.

Example 3-11: ENERGY STAR® Roofing Products

Question: I am a salesperson who represents several roofing products. Many of them are on the ENERGY STAR® list published by the U.S. Environmental Protection Agency (EPA) for cool roofing materials. Is this sufficient to meet the Energy Code?

Answer: No. ENERGY STAR has different requirements than the Energy Code for reflectance and no requirements for emittance. Per §10-113, the Cool Roof Rating Council (www.coolroofs.org) is the only entity recognized by the California Energy Commission to determine what qualifies as a cool roof.

Example 3-12: Certifying Products with the Cool Roof Rating Council (CRRC)

Question: How does a product get CRRC cool roof certification?

Answer: CRRC publishes its certification procedures in the CRRC-1 Program Manual, available for free at www.coolroofs.org or by calling CRRC at (866) 465-2523 (toll free within the USA) or (510)-485-7176. Anyone new to the certification process and wishing to have one or more products certified should contact CRRC by phone or by email at info@coolroofs.org. Working with CRRC is strongly recommended; staff walks interested parties through the procedures.

Example 3-13: Reflectance vs. Emittance

Question: I understand reflectance, but what is emittance?

Answer: Material that reflects the sun's energy will still absorb some of that energy as heat; there are no perfectly reflecting materials being used for roofing. The absorbed heat is given off (emitted) to the environment in varying amounts depending on the materials and surface types. This emittance is given a value between 0 and 1, and this value represents a comparison (ratio) between what a given material or surface emits and what a perfect blackbody emitter would emit at the same temperature.

A higher emittance value means more energy is released from the material or surface; scientists refer to this emitted energy as *thermal radiation*. *Emittance* is a measure of the relative efficiency with which a material, surface, or body can cool itself by radiation. Lower-emitting materials become relatively hotter due to holding in heat. Roof materials with low emittance hold onto more solar energy as heat, and that held heat can be given off downward into the building. More heat in the building increases the need for air conditioning for comfort. A cool roof system that reflects solar radiation (has high reflectance) and emits thermal radiation well (has high emittance) will result in a cooler roof and a cooler building with lower air-conditioning costs.

3.4.3.2 Mandatory Requirements

- **Field-Applied Liquid Coatings §110.8(i)4**

There are several liquid products, including elastomeric coatings and white acrylic coatings, that qualify for field-applied liquid coatings. The Energy Code specifies minimum performance and durability requirements for field-applied liquid coatings. These requirements do not apply to industrial coatings that are factory-applied, such as metal roof panels. The requirements address elongation, tensile strength, permeance (rate of water vapor transmission), and accelerated weathering. The requirements depend on the type of coating and are described here in greater detail. Liquid roof coatings applied to low-sloped roofs in the field as the top surface of a roof covering shall comply with the following mandatory requirements and descriptions.

- **Aluminum-Pigmented Asphalt Roof Coatings.** Aluminum-pigmented coatings are silver-colored coatings that are commonly applied to modified bitumen and other roofing products. The coating has aluminum pigments that float to the surface of

the coating while it is setting, providing a shiny and reflective surface. Because of the shiny surface and the physical properties of aluminum, these coatings have a thermal emittance below 0.75, which is the minimum rating for prescriptive compliance.

This class of field-applied liquid coatings shall be applied across the entire surface of the roof and meet the dry mil thickness or coverage recommended by the manufacturer, depending on the substrate on which the coating will be applied. The aluminum-pigmented asphalt roof coatings shall be manufactured in accordance with ASTM D2824. Standard specification is also required for aluminum-pigmented asphalt roof coatings, non-fibered, asbestos-fibered, and fibered without asbestos that are suitable for application to roofing or masonry surfaces by brush or spray, and installed in accordance with ASTM D3805, *Standard Guide for Application of Aluminum-Pigmented Asphalt Roof Coatings*.

- **Cement-Based Roof Coatings.** This class of coatings consists of a layer of cement that may be applied to almost any type of roofing. Cement-based coatings shall be applied across the entire roof surface to meet the dry mil thickness or coverage recommended by the manufacturer. Cement-based coatings shall be manufactured to contain no less than 20 percent Portland cement and meet the requirements of ASTM D822, ASTM C1583, and ASTM D5870.
- **Other Field-Applied Liquid Coatings.** Other field-applied liquid coatings include elastomeric and acrylic-based coatings. These coatings must be applied across the entire roof surface to meet the dry mil thickness or coverage recommended by the manufacturer, depending on the substrate on which the coating will be applied. The field-applied liquid coatings must be tested to meet several performance and durability requirements as specified in Table 110.8-C of the Energy Code or the minimum performance requirements of ASTM C836, D3468, or D6694, whichever are appropriate to the coating material.

3.4.3.3 Prescriptive Requirements §150.1(c)11

Steep-sloped and low-sloped energy-efficient cool roofs are prescriptively required in some climate zones. The prescriptive requirement is based on an aged solar reflectance and thermal emittance tested value from the Cool Roof Rating Council (CRRC). If a cool roof is being installed to comply with the Energy Code, it must meet mandatory product and labeling requirements.

Table 3-7: Prescriptive Cool Roof Requirements

Roof Type	Climate Zone	Minimum Three-Year Aged Solar Reflectance	Minimum Thermal Emittance	Minimum SRI
Steep-sloped	10 through 15	0.20	0.75	16

Roof Type	Climate Zone	Minimum Three-Year Aged Solar Reflectance	Minimum Thermal Emittance	Minimum SRI
Low-sloped	13 and 15	0.63	0.75	75

Source: California Energy Commission

There are two exceptions to meeting these prescriptive requirements:

1. Roof area with building-integrated photovoltaic panels or building-integrated solar thermal panels.
- **OR**
2. Roof constructions that have a weight of at least 25 lb/ft².
- The project could choose to pursue the performance approach and trade off the prescriptive cool roof requirements. See Section 3.6 and Chapter 8 for more on the performance approach.

3.4.3.4 Compliance and Enforcement

The plans examiner should ensure that the aged solar reflectance and thermal emittance values documented on the CF1R-ENV-04 are specified on the building plans at the time of permit application.

The inspector can verify that the values on the CRRC label for the installed roof product meet or exceed the aged solar reflectance and thermal emittance values on the CF1R compliance document.

Note for Building Inspectors: If a manufacturer does not obtain a CRRC certificate for its roofing products, the following default aged solar reflectance and thermal emittance values must be used for compliance:

1. For asphalt shingles: 0.08 aged SR and 0.75 TE
2. For all other roofing products: 0.10 aged SR and 0.75 TE

3.4.4 Radiant Barriers §110.8(j), §150.1(c)2

A radiant barrier is a reflective material that reduces radiant heat transfer into the attic caused by solar heat gain in the roof.

3.4.4.1 Mandatory Requirements §110.8(j)

When a radiant barrier is installed, the product must meet mandatory requirements in §110.8(j).

The radiant barrier must have an emittance of 0.05 or less. The product must be tested according to ASTM C1371 or ASTM E408, and must be certified by the

Bureau of Household Goods and Services (BHGS) and listed in its Consumer Guide and Directory of Certified Insulation Material, at https://bhgs.dca.ca.gov/consumers/ti_directory.pdf.

3.4.4.2 Prescriptive Requirements §150.1(c)2, RA4.2.1

The prescriptive requirements call for Option C vented attics to have a radiant barrier in climate zones 2 through 15, while Option B vented attics only require a radiant barrier in climate zones 2, 3, and 5 through 7.

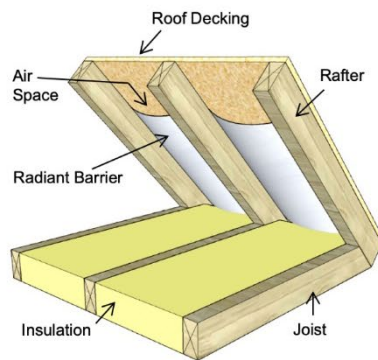
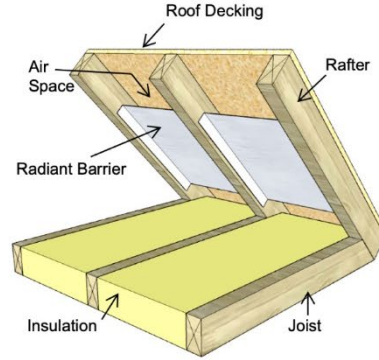
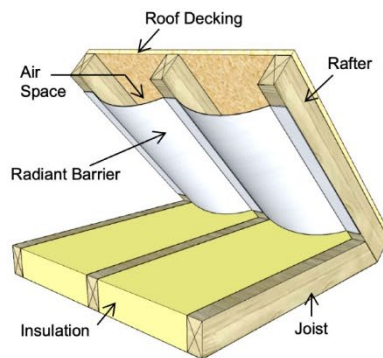
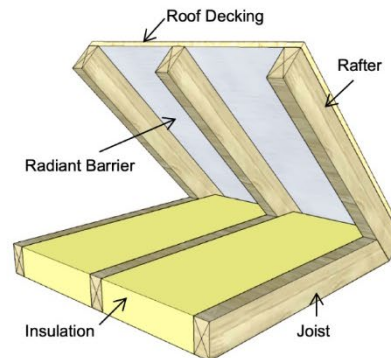
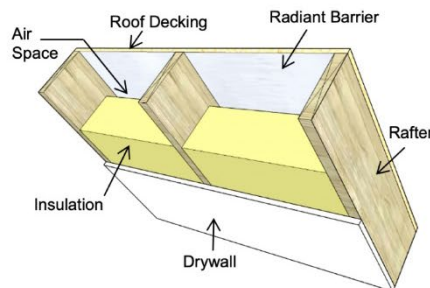
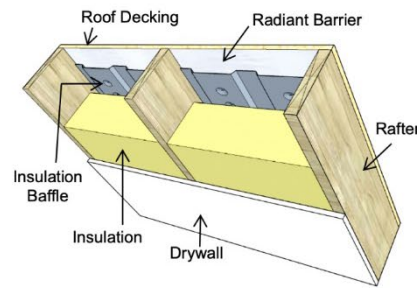
Installation. The most common way of meeting the radiant barrier requirement is to use roof sheathing that has a radiant barrier bonded to it by the manufacturer. Some oriented strand board (OSB) products have a factory-applied radiant barrier. The sheathing is installed with the radiant barrier (shiny side) facing down toward the attic space.

Alternatively, a radiant barrier material that meets the same ASTM test and moisture perforation requirements that apply to factory-laminated foil can be field-laminated. Field lamination must use a secure mechanical means of holding the foil-type material to the bottom of the roof decking such as staples or nails that do not penetrate all the way through the roof deck material. Roofs with gable ends must have a radiant barrier installed on the gable ends to meet the radiant barrier requirement.

Other acceptable methods are to drape a foil type radiant barrier over the top of the top chords before the sheathing is installed, stapling the radiant barrier between the top chords after the sheathing is installed, and stapling the radiant barrier to the underside of the truss/rafters (top chord). For these installation methods, the foil must be installed with spacing requirements as described in Reference Appendices, Residential Appendix RA4.2.1.

Installation of radiant barriers is somewhat more challenging in the case of closed rafter spaces, particularly when roof sheathing is installed that does not include a laminated foil-type radiant barrier. Radiant barrier foil material may be field-laminated after the sheathing has been installed by “laminating” the foil to the roof sheathing between framing members. This construction type is described in the Reference Appendices, Residential Appendix RA4.2.1.1. See Figure 3-13 for drawings of radiant barrier installation methods.

For closed rafter spaces, such as a cathedral ceiling, the required air space for radiant barriers shall be provided and must meet the ventilation requirements of California Building Code (CBC), Title 24, Part 2.5, §R806.1.

Figure 3-13: Methods of Installation for Radiant Barriers**Method 1: Radiant Barrier Draped Over Top of Truss/Rafter****Method 2: Radiant Barrier Attached Between Truss/Rafters****Method 3: Radiant Barrier Attached To Bottom of Truss/Rafter****Method 4: Radiant Barrier Attached To Underside of Roof Deck****Method 5: Radiant Barrier Attached to Underside of Roof Deck with Air Space****Method 6: Radiant Barrier Attached to Underside of Roof Deck with Baffle**

Source: California Energy Commission

Radiant Barriers in the Performance Approach

In the performance approach, radiant barriers are modeled apart from the U-factor. The duct efficiency also is affected by the presence of a radiant barrier when using the performance approach. See more in Section 3.6 and Chapter 8.

3.4.5 Vapor Retarder §150.0(g) and RA4.5.1

When is a vapor retarder required?

In climate zones 14 and 16, a continuous Class I or Class II vapor retarder, lapped or joint sealed, must be installed on the conditioned-space side of all insulation in all exterior walls, on the roof decks of vented attics with above-deck or below-deck air-permeable insulation, and in unvented attics with air-permeable insulation.

Buildings with unvented or controlled-ventilation crawl spaces in all climates zones must have a Class I or Class II vapor retarder placed over the earth floor of the crawl space to reduce moisture entry and protect insulation from condensation in accordance with Reference Appendices, Residential Appendix RA4.5.1.

3.4.5.1 Product Requirements

Vapor retarder class is a measure of the ability of a material or assembly to limit the amount of moisture that passes through the material or assembly. Vapor retarder classes are defined in Section 202 of the California Building Code (CBC). Testing for vapor retarder class is defined using the desiccant method of ASTM E96.

1. Class I: 0.1 perm or less
2. Class II: $0.1 < \text{perm} \leq 1.0$ perm
3. Class III: $1.0 < \text{perm} \leq 10$ perm

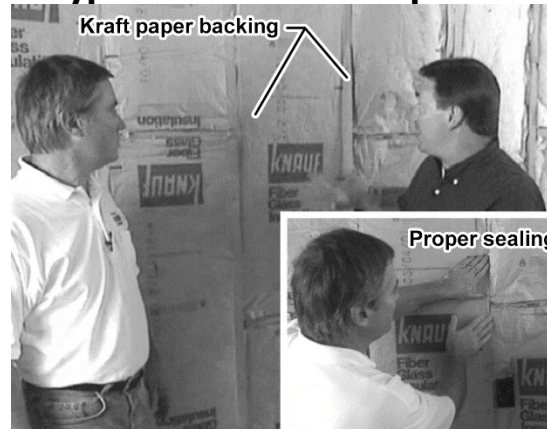
There are many product types having tested vapor retarder performance. Some common examples include the following:

1. Foil and other facings on gypsum board can provide moisture resistance, and product literature should always be checked to ensure conformance to ASTM E96.
2. The kraft paper used as facing on thermal batt insulation material is typically a Class II vapor retarder. Faced batts may have flanges for fastening to assembly framing. Fastening flanges may be face- or inset-stapled or not stapled at all, as the flanges provide no moisture control. Face stapling of flanged thermal batts helps ensure the insulation material is installed fully and properly within the framed cavity. Flangeless batts are also common and require no fastening as these materials maintain installation integrity through friction-fitting within the cavity of framed assemblies. In all cases, the insulation must be installed properly. See Figure 3-14.
3. Interior painted surfaces may also serve as vapor retarders if the paint product has been tested and shown to comply with the vapor retarder requirements. The effectiveness of vapor retarder paint depends upon the installed thickness (in mils). These products often require more than one layer to achieve the tested perm rating, and care must be shown by the installer of the paint and for inspection by the building official.

4. Closed-cell spray polyurethane foam (ccSPF) products can provide Class I or Class II vapor retarder performance, depending on thickness.

For all types of vapor retarders, care should be taken to seal penetrations, such as electrical outlets on exterior walls.

Figure 3-14: Typical Kraft-Faced Vapor Retarder Facing



Source: California Energy Commission

3.5 Insulation Products

The Energy Code encourages the use of energy-saving techniques and designs for showing compliance. Insulation is one of the least expensive requirements to improve building energy efficiency. Insulation requires no maintenance, helps improve indoor comfort, and provides excellent sound control. Adding extra insulation later is more expensive than maximizing insulation levels at the beginning of construction. Innovative construction techniques and building products are being used more often by designers and builders who recognize the value of energy-efficient, high-performance buildings.

When the performance compliance method is used, an energy credit can be taken for design strategies that reduce building energy use below the standard design energy budget (compliance credit). Some strategies may require third-party verification by a HERS Rater; others do not. For more on the performance method, see Section 3.6 and Chapter 8.

Table 3-8: Relevant Sections in the Energy Code

	MANDATORY	PRESCRIPTIVE	PERFORMANCE
Insulation	§110.8(a) - (d), §110.8(g) - (h), §150.0(a) - (d), §150.0(f)	§150.1(c)1 Table 150.1-A	§150.1(a), §150.1(b)

3.5.1 Types of Insulation Products

There are four basic types of insulation or "insulation systems" installed in residential buildings: batt and blanket, loose-fill, spray polyurethane foam (SPF), and rigid insulation. The use varies based on the design and type of construction.

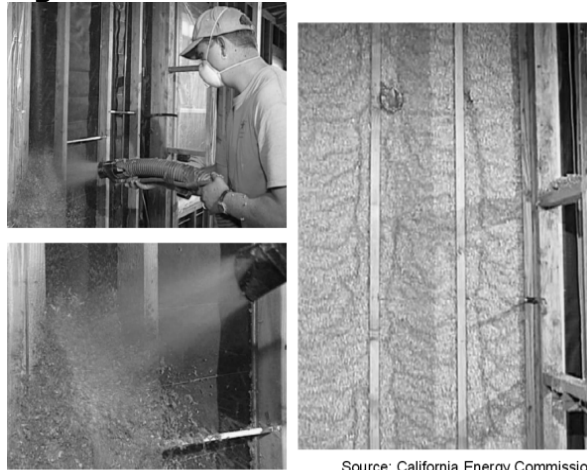
3.5.1.1 Batt and Blanket

- Batt and blanket insulation are made of mineral fiber and mineral wool (processed fiberglass, rock, slag wool); animal wool or cotton-based products; or cellulose materials. These products are used to insulate below floors, above ceilings, below roofs, and within walls. They offer ease of installation with R-values set by the manufacturer based on size and thickness. They are available with facings, some serve as vapor retarders, and have flanges to aid in installation to framed assemblies. Many are available as unfaced material and can be easily friction-fitted into framed cavities.
- Batt and blanket insulation allow easy inspection, and installation errors can readily be identified and remedied, including breeches in the air barrier system that allow air leakage.

Note for Contractors/Installers: Care should always be taken to install insulation properly, filling the entire cavity and butting ends or sides of the batt material to ensure uniformity of installation. Batt and blanket insulation material must be delaminated or cut to allow for wiring, plumbing, and other penetrations within the cavity. See Section 3.5.

3.5.1.2 Loose-Fill Insulation

Figure 3-15: Cellulose-Insulated



Source: California Energy Commission

Loose-fill is insulation that has a pneumatic or blown installation process, including cellulose, fiberglass, mineral wool and natural wool (animal or cotton-based products). Blown wall insulation can be an effective way to deal with the irregularities of wall cavities, especially the spaces around pipes, electric cables, junction boxes, and other equipment embedded in wall cavities (see Figure 3-15). The R-value of blown wall insulation material installed in closed cavities is determined by the installed thickness and density. This differs from manufactured products such as fiberglass or mineral wool batts for which the R-value has been tested and arrives at the construction site in preformed lengths and thicknesses with set R-values.

When installed in floors, walls, and other assemblies, these fibrous insulations are held in place in one of three ways:

1. Preinstalled netting or fabric
2. Use of existing cavity walls
3. Use of integral adhesives

Note for Building Inspectors: Blown wall insulation must be thoroughly checked to ensure the R-value is achieved. R-value depends on the installed density of the material at the building site, and the building official should ensure that the installed density meets manufacturer specifications. See Section 3.5.

In closed cavities:

- A line of sight down a wall section can hide imperfections in the installation, leading to underachieving stated R-values.
- Depressions and voids within the insulated cavity are areas lacking in R-value performance.

- Where netting is used, overspraying can result in a higher installed density (higher R-value) but can be troublesome for attaching gypsum board to wall framing.
- Where cavities have been underfilled, there may be voids or “soft” areas under the netting. These areas must be corrected by adding insulation, or the area must be removed, and new material must be blown into the cavity.

In open cavities (attic floor or open wall):

- No netting or preexisting wall cladding is needed (Figure 3-16).
- In open horizontal applications, such as attic floors, no adhesives are used, and the R-value is verified by the weight per square foot.
- In open vertical applications, integral adhesives are used to hold the fibers in place. Water-activated adhesives are used for moist-spray cellulose, and water or polymer adhesives are used for fiberglass loose-fill applications. The fiber and/or adhesive formulation cause the insulation to adhere to itself and stick to surfaces of the wall cavity.
- Excess insulation that extends past the wall cavity is scraped off and recycled.

Figure 3-16: Attic Floor

Source: California Energy Commission

3.5.1.3 Spray Polyurethane Foam (SPF)

- SPF is a two-part, liquid-foamed thermoset plastic (such as polyurethane). Polyurethane is formed by the reaction of an isocyanate and a polyol. Blowing agents, catalysts, and surfactants are added to develop a cellular structure before the polyurethane mixture cures. At application, the SPF material forms in place to provide insulation, an air seal, and, in closed-cell SPF, an integral vapor retarder and water barrier.
- SPF insulation is a two-component reactive system mixed at a spray gun or a single-component system that cures by exposure to humidity. The liquid is sprayed through a nozzle into the wall, roof, ceiling, and floor cavities. SPF insulation can be formulated to have specific physical properties, such as density, compressive strength, fire resistance, and R-value.

- SPF insulation is spray-applied to adhere fully to the substrate and other framing faces to form a complete air seal within the construction cavities.

Note for Contractors/Installers: SPF must be separated from the interior of the building, including attic spaces, by an approved thermal barrier complying with Section 316.4 of the California Residential Code (CRC).

- There are two common types of SPF insulation:

Figure 3-17: Open-Cell SPF Installed in Wall Cavity



Source: SPFA

- A. Low-Density Open-Cell SPF (ocSPF) Insulation:** A spray-applied polyurethane foam insulation having an open cellular structure resulting in an installed nominal density of 0.4 to 1.5 pounds per cubic foot (pcf), ocSPF has been assigned a default R-value of 3.6 per inch for compliance, but some products can achieve higher R-values. The ocSPF insulation is sprayed then expands to fill the framed cavity (Figure 3-17). Excess insulation may be trimmed by a special tool to simplify interior cladding installation. The average thickness of the foam insulation must meet or exceed the required R-value. Depressions in the foam insulation surface shall not be greater than 1/2-inch of the required thickness, provided these depressions do not exceed 10 percent of the surface area being insulated. Note: If using the default R-value of 3.6 per inch, the entire wall cavity must be filled to achieve the mandatory minimum wall insulation requirements for 2x4 and 2x6 framing.

Figure 3-18: Closed-Cell SPF Installation in a Wall Cavity



Source: SPFA

B. Medium-Density Closed-Cell SPF (ccSPF) Insulation: A spray-applied polyurethane foam insulation having a closed cellular structure resulting in an installed nominal density of greater than 1.5 to less than 2.5 pounds per cubic foot (pcf), ccSPF has been assigned a default R-value of 5.8 per inch for compliance, but some products can achieve higher R-values. The average thickness of the foam insulation must meet or exceed the required R-value. Depressions in the surface of the foam insulation shall not be greater than 1/2-inch of the required thickness at any given point of the surface area being insulated. ccSPF is not required to fill the cavity (Figure 3-18).

Note for Building Inspectors: SPF R-value depends on the installed thickness, and the building official should ensure the thickness and uniformity of the SPF material within each cavity of framed assemblies meets manufacturer specifications.

Table 3-9: Required Thickness of SPF Insulation to Achieve Default R-Values
Equation 3-2: Alternative Calculation for Total R-Value:

<ul style="list-style-type: none">Thickness of insulation multiplied by	<ul style="list-style-type: none">“Tested R-value per inch” as certified by the Department of Consumer Affairs, Bureau of Household Goods and Services
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Overall assembly U-factors are determined by selecting the assembly type, framing configuration, and cavity insulation rating from the appropriate Reference Appendices, Joint Appendix JA4 table, other approved method specified in JA4, or using the Energy Commission-approved compliance simulation software.

3.5.1.4 Rigid Insulation

- Rigid board insulation sheathing is made from fiberglass, mineral wool, expanded polystyrene (EPS), extruded polystyrene (XPS), polyisocyanurate (ISO), or polyurethane (PUR). It varies in thickness, and some products can provide up to R-6 per inch of thickness.

Figure 3-19: Properly Installed Rigid Insulation with Sealant Tape



Source: U.S. Environmental Protection Agency

This type of insulation is used for above-roof decks, exterior walls, cathedral ceilings, basement walls; as perimeter insulation at concrete slab edges; and to insulate special framing situations such as window and door headers and around metal seismic bracing. Rigid board insulation may also be integral to exterior siding materials. Properly sealed rigid insulation can be used continuously across an envelope surface to reduce air infiltration and exfiltration, and thermal bridging at framing.

Note for Contractors/installers: Proper installation of continuous rigid insulation may include button cap nails, furring strips, flashing, sealant tape, and design of the drainage plane. See Figure 3-19.

The 2022 California Building Code (CBC) provides guidance on fastener penetration depth, diameter, and spacing for exterior foam sheathing in Section R703.11.2. California Residential Code (CRC) Table 703.15.1 shows the fastener spacing for cladding attachment over foam sheathing to wood framing.

3.5.2 Insulation Product Requirements §110.8(a)

Manufacturers must certify that insulating materials comply with the *California Quality Standards for Insulating Materials* (California Reference Standards Code [CCR], Title 24, Part 12, Chapters 12-13), which ensure that insulation sold or installed in

California performs according to stated R-values and meets minimum quality, health, and safety standards.

Note for Building Inspectors: Builders and enforcement agencies shall use the California Department of Consumer Affairs *Directory of Certified Insulation Material* to verify the certification of the insulating material. If an insulating product is not listed in the current edition of the directory, contact the Department of Consumer Affairs, Bureau of Household Goods and Services, at (916) 999-2041 or by email at HomeProducts@dca.ca.gov.

3.5.2.1 Urea Formaldehyde Foam Insulation §110.8(b)

The mandatory requirements restrict the use of urea formaldehyde foam insulation. The restrictions are intended to limit human exposure to formaldehyde, a volatile and harmful organic chemical.

If foam insulation is used that has urea formaldehyde, it must be installed on the exterior side of the wall (not in the cavity of framed walls), and a continuous vapor retarder must be placed in the wall construction to isolate the insulation from the interior of the space. The vapor retarder must be 4-mil- thick (0.1 mm) polyethylene or equivalent.

3.5.2.2 Flame Spread Rating of Insulation §110.8(c)

The *California Quality Standards for Insulating Materials* requires that exposed facings on insulation material be fire resistant and tested and certified not to exceed a flame spread index of 25 and a smoke development index of 450. Insulation facings must be in contact with the finished assembly surface or they are considered exposed applications and cannot be installed. Flame spread indexes and smoke development indexes are shown on the insulation or packaging material or may be obtained from the manufacturer.

3.5.3 Ceiling and Roof Insulation §110.8(d), §150(a)

3.5.3.1 Loose Fill Insulation in the Attic §150.0(b)

Loose fill insulation must be blown in evenly, and insulation levels must be documented on the certificate of installation (CF2R). The insulation level can be verified by checking that the depth of insulation conforms to the manufacturer's coverage chart for achieving the required R-value. The insulation also must meet the manufacturer's specified minimum weight per ft² for the corresponding R-value.

Note for Contractors/Installers: When installing loose fill insulation, the following guidelines should be followed:

1. For wood trusses that provide a flat ceiling and a sloped roof, the slope of the roof should be 4:12 or greater to provide adequate access for installing the insulation. Insulation thickness near the edge of the attic will be

reduced with all standard trusses, but this is acceptable as long as the average thickness is adequate to meet the minimum insulation requirement.

2. If the ceiling is sloped (for instance, with scissor trusses), loose fill insulation can be used as long as the slope of the ceiling is no more than 4:12. If the ceiling slope is greater than 4:12, loose fill should be used only if the insulation manufacturer will certify the installation for the slope of the ceiling.
3. At the apex of the truss, a clearance of at least 30 inches should be provided to simplify installation and inspection.

3.5.3.2 Wet Insulation Systems §110.8(h)

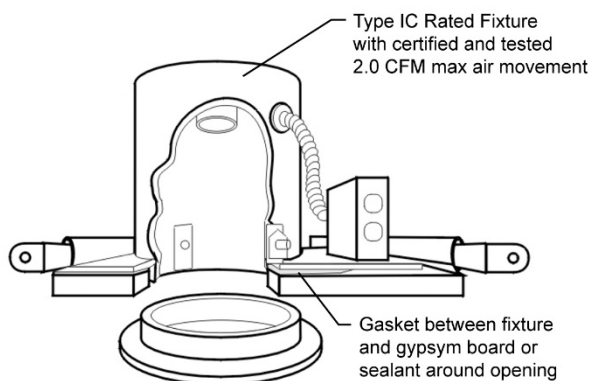
Wet insulation systems are roofing systems where the insulation is installed above the waterproof membrane of the roof. Water can penetrate this insulation material and affect the energy performance of the roofing assembly in wet and cool climates. In climate zones 1 and 16, the insulating R-value of continuous insulation materials installed above the waterproof membrane of the roof must be multiplied by 0.8, and installers must use the resulting value in choosing the table column in Reference Appendices, Joint Appendix JA4 for determining assembly U-factor (when using the Joint Appendix JA4 table to comply). See the footnotes for Tables 4.2.1 through 4.2.7 in the Reference Appendices, Joint Appendix JA4.

3.5.3.3 Recessed Luminaires §150.0(k)1C

Luminaires recessed in insulated ceilings can create thermal bridging through the assembly. Not only does this degrade the performance of the ceiling assembly, but it can permit condensation on a cold surface of the luminaire if exposed to moist air, as in a bathroom. Refer to the Lighting Chapter 6 for more information regarding the applicable requirements for recessed luminaires.

Luminaires recessed in insulated ceilings must meet three requirements.

1. They must be listed as defined in the Article 100 of the California Electric Code for zero clearance insulation contact (IC) by Underwriters Laboratories or other testing/rating laboratories recognized by the International Code Council (ICC). This enables insulation to be in direct contact with the luminaire.
2. The luminaire must have a label certified as per §150.0(k)1Cii for airtight (AT) construction. Airtight construction means that leakage through the luminaire will not exceed 2.0 cfm when exposed to a 75 Pa pressure difference, when tested in accordance with ASTM E283.
3. The luminaire must be sealed with a gasket or caulk between the housing and ceiling.

Figure 3-21: IC-Rated Luminaire (Light Fixture)

Source: California Energy Commission

3.5.3.4 Mandatory Requirements

Wood-framed roof/ceiling construction assemblies must have at least R-22 insulation or a maximum U-factor of 0.043 based on 16-inch-on-center wood-framed rafter roofs, as determined from Reference Appendices, Joint Appendix JA4. Some areas of the roof/ceiling can be greater than the maximum U-factor if other areas have a U-factor lower than the requirement and the weighted average U-factor for the overall ceiling/roof is 0.043 or less.

Metal-framed and roof/ceiling constructions other than wood-framed must have a U-factor of 0.043 or less to comply with the mandatory requirement. If the insulation is not penetrated by framing, such as rigid insulation laid over a structural deck, then the rigid insulation can actually have a rated R-value of less than R-22 so long as the total roof/ceiling assembly U-factor is not greater than U-0.043.

Newly constructed attics must have roof deck insulation in climate zones 4 and 8 through 16. Insulation may either be above or below the roof deck so long as the area-weighted average U-factor of the roof assembly is not greater than 0.184. This is equivalent to R-3 or R-4 insulation depending on the location of the insulation (above or below the roof deck) and the roof type. See Table 3-10 for examples of assemblies that can be constructed to meet the requirement. Exceptions to the mandatory roof deck insulation include: (1) if the space conditioning system air handler and ducts are located entirely in conditioned space (NOTE: Duct systems located in conditioned space can be uninsulated if specific conditions are met, as explained in Section 4.4.1 (§150.0(m)1B)), or (2) if no greater than 12 linear feet of supply duct, including the air handler and plenum are located in unconditioned space.

Table 3-10: Examples of Wood-Framed Roof Assemblies and U-Factors, Assuming a Vented Attic

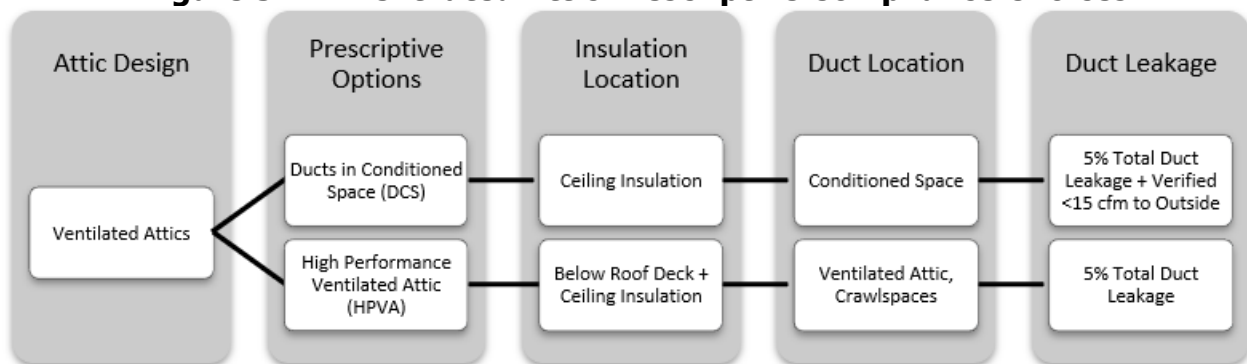
Roofing	Above Deck Continuous Insulation	Below Deck Cavity Insulation	U-Factor ¹
Tile (10 PSF w/ airgap)	R-3	n/a	0.180
Tile (10 PSF w/ airgap)	n/a	R-3	0.184
Tile (10 PSF no airgap)	R-4	n/a	0.175
Tile (10 PSF no airgap)	n/a	R-4	0.181
Asphalt Shingle	R-4	n/a	0.178
Asphalt Shingle	n/a	R-4	0.184
Metal Tile	R-3	n/a	0.182
Metal Tile	n/a	R-4	0.159

¹U-factor based on 2x4 at 24 inch on-center roof framing.

Source: California Energy Commission

3.5.3.5 Prescriptive Requirements §150.1(c) and Table 150.1-A

The 2022 Energy Code is designed to offer flexibility to the builders and designers of residential newly constructed buildings in terms of achieving the intended energy efficiency targets. As such, the Energy Code offers several options for achieving one of two design objectives related to improving energy performance of homes built with ventilated attics in climate zones 4, 8-16, as shown in Figure 3-22.

Figure 3-22: Ventilated Attic Prescriptive Compliance Choices

Source: California Energy Commission

High Performance Ventilated Attic (HPVA). This approach reduces temperature differences between the attic space and the conditioned air being transported through ductwork in the attic. The package consists of insulation below

the roof deck (Option B) in addition to insulation at the ceiling, R-6 or R-8 ducts, and 5 percent total duct leakage of the nominal air handler airflow.

Ducts in Conditioned Space (DCS). Ducts and air handlers are within the thermal and air barrier envelope of the building.

Note for Contractors/Installers: The Ducts in Conditioned Space (Option C) requires field verification by a HERS Rater to meet the prescriptive requirement.

All the prescriptive requirements for HPVA or DCS are based on the assumption that the home is built with the following construction practices:

1. The attic is ventilated with an appropriate free vent area as described below.
2. The roof is constructed with standard wood rafters and trusses.
3. For HPVA, the outermost layer of the roof construction is either tiles or a roofing product installed with an air gap between it and the roof deck.
4. The air handler and ducts are in the ventilated attic for HPVA and are in conditioned space for DCS.
5. The air barrier is located at the ceiling (excludes “cathedral” sealed attic roof/ceiling systems).

If a building design does not meet all of these specifications, it must comply through the performance approach.

Example 3--14: Cathedral Ceilings

Question: If 5 percent of a roof will be a cathedral ceiling, can it still comply under the prescriptive requirements?

Answer: No. The entire attic must be a ventilated space with the building air barrier located at the ceiling with standard wood rafter trusses to comply with the prescriptive requirements. This project must comply through the performance approach.

Example 3-15: Unventilated Attics

Question: Does an unventilated attic with insulation at the roof deck comply under the prescriptive requirements?

Answer: No. The entire attic must be a ventilated space with the building air barrier located at the ceiling with standard wood rafter trusses to comply with the prescriptive requirements. This project must comply through the performance approach.

Example 3-16: Insulation Above the Roof Deck

Question: Does a ventilated attic with insulation above the roof deck comply under the prescriptive requirements?

Answer: No. The insulation must be located below the roof deck between the roof rafters to comply with the prescriptive requirements. If insulation is above the roof deck, the project must comply through the performance approach.

Example 3-17: Asphalt Shingles

Question: A home with asphalt shingle roofing, having no air gap, has a ventilated attic with insulation installed below the roof deck between the roof rafters (HPVA) and at the ceiling meeting prescriptive insulation levels. Does this home comply with the prescriptive requirements?

Answer: No. The roofing product must be of a type that is installed with an air gap between the product and the roof deck, such as concrete tile, to comply with the prescriptive requirements. If a roofing product with no air gap between the product and the roof deck is installed, the project must comply through the performance approach.

Example 3-18: Gable Ends in High Performance Ventilated Attics

Question: In addition to the roof underdeck, do gable end walls in high performance ventilated attics (HPVA) need to be insulated?

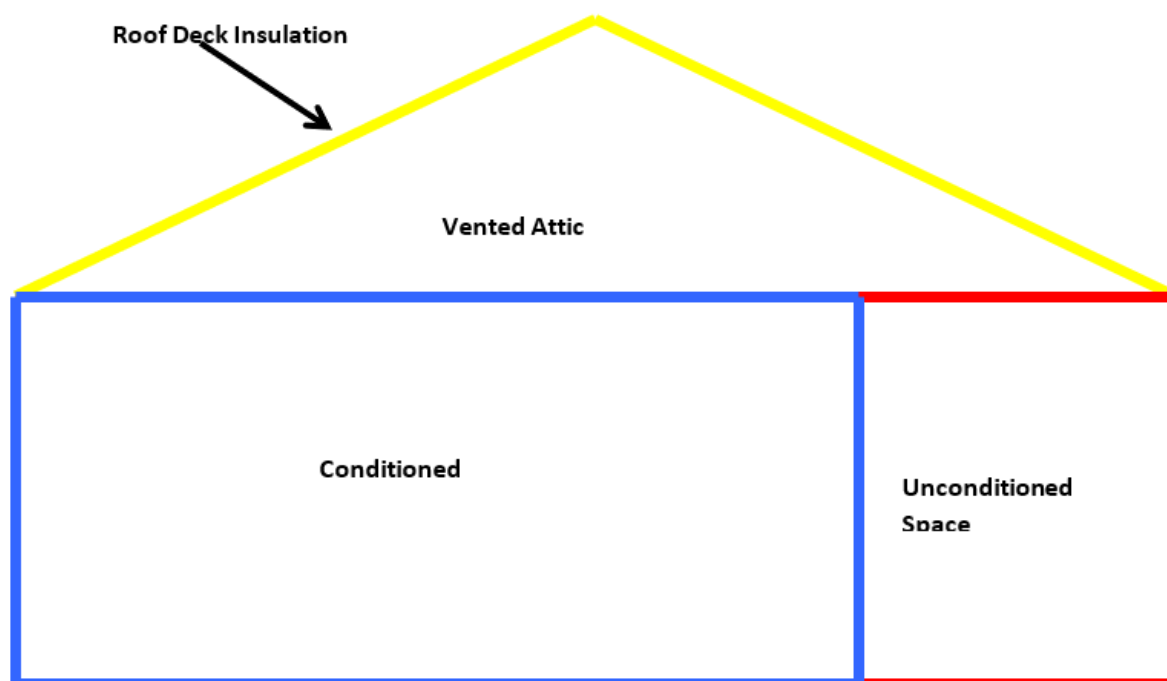
Answer: No. Gable end walls do not need to be insulated when designing and installing a HPVA.

Example 3-19: Attic Insulation Placement

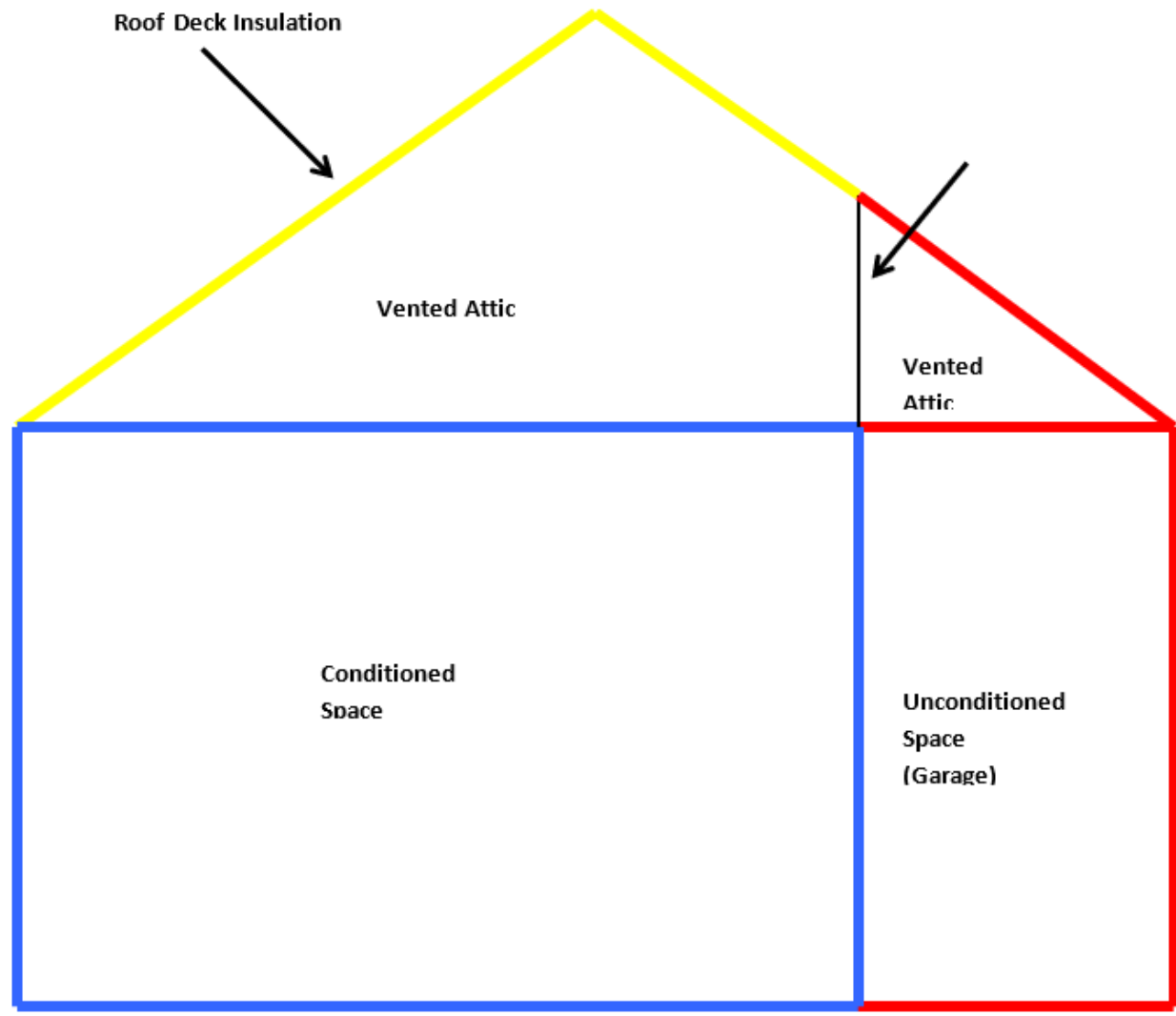
Question: When installing roof/ceiling insulation, does the insulation need to be installed on the entire roof/ceiling, including areas over unconditioned space?

Answer: It depends. The insulation should be installed at the roof/ceiling in one of the following ways:

(1) If the attic is an open or undivided space, then the entire roof/ceiling should be insulated. This includes portions of the roof/ceiling over an unconditioned space such as a garage.



(2) If the attic has a continuous air barrier separating the attic over unconditioned space from the attic over conditioned space, then only the portions of the roof/ceiling over conditioned space should be insulated. It is recommended, but not required, that the air barrier also be insulated.



3.5.3.6 High Performance Ventilated Attics §150.1(c).1

This section describes the prescriptive requirements and approaches necessary for HPVA as they relate to roof/ceiling insulation. HVAC aspects of the HPVA including duct insulation and duct leakage are described in Chapter 4. Requirements and approaches to meet the ducts in conditioned space (DCS) are described in Chapter 4 of this manual.

Section 150.1(c).1 requires different values of roof and ceiling insulation, depending on whether the HPVA (Option B) or DCS (Option C) is chosen. Figure 3-23 shows a prescriptive requirements checklist for each option based on Tables 150.1-A.

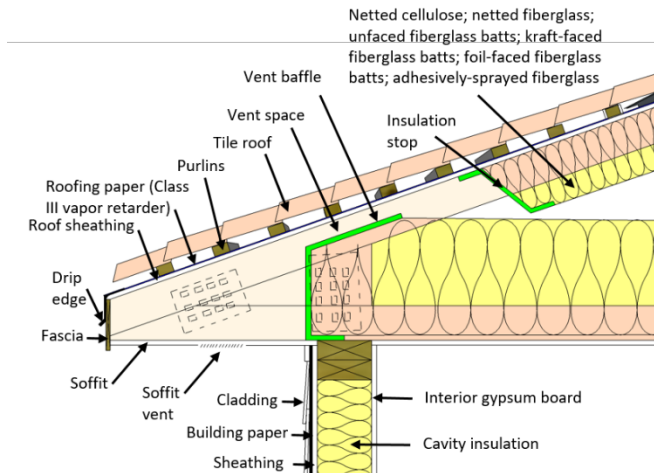
Figure 3-23: Prescriptive Insulation Options

High Performance Ventilated Attics Option B ¹	Ducts in Conditioned Space Option C
<input type="checkbox"/> Vented attic <input type="checkbox"/> R-19 (CZ 4, 8-16) below roof deck batt, spray in cellulose/fiberglass secured with netting, or spray foam <input type="checkbox"/> R-38 (CZ 1, 2, 4, 8-16) ceiling insulation or R-30 (CZ 3, 5-7) <input type="checkbox"/> Radiant barrier (CZ 2, 3, 5-7) <input type="checkbox"/> Air space between roofing and the roof deck <input type="checkbox"/> R-6 or R-8 duct insulation (climate zone specific) <input type="checkbox"/> 5% total duct leakage	<input type="checkbox"/> Vented attic <input type="checkbox"/> R-38 (CZ 1, 11-16) ceiling insulation or R-30 (CZ 2-10) <input type="checkbox"/> R-6 or R-8 ducts (climate zone-specific) <input type="checkbox"/> Radiant barrier (CZ 2-15) <input type="checkbox"/> HERS-verified ducts in conditioned space (5% Total Duct Leakage + Verified <15 cfm to Outside)
<ul style="list-style-type: none"> • Table 150.1-A • Assembly Option B 	<ul style="list-style-type: none"> • Table 150.1-A/B • Assembly Option C

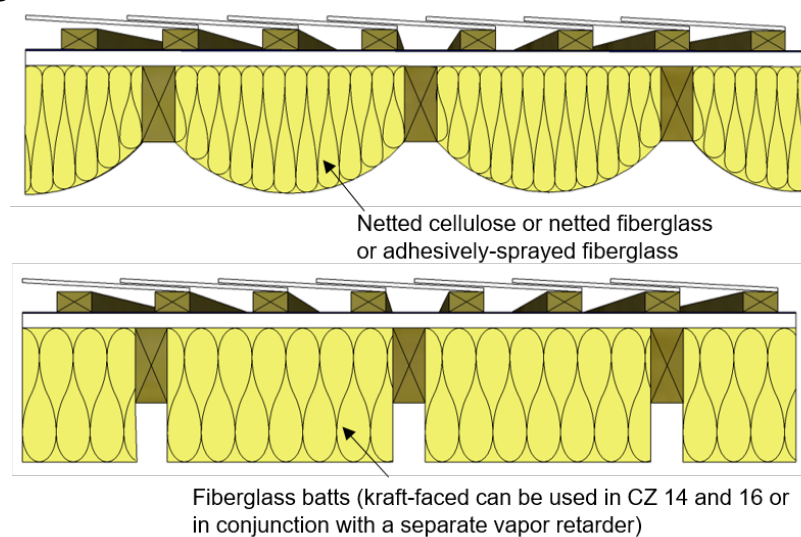
Note: 1 Option B is the standard design used to set the energy budget for the performance approach.

Source: California Energy Commission

- **Below Roof Deck Insulation Option B.** In a vented attic, air-permeable or air-impermeable insulation (batt, spray foam, loose-fill cellulose, or fiberglass) should be placed **directly** below the roof deck between the truss members and secured in place to provide a thermal break for the attic space. Insulation must be in direct contact with the roof deck and secured by the insulation adhesion, facing, mechanical fasteners, wire systems, a membrane material, or netting. Batts supported with cabling or other mechanical methods from below shall have supports that are less than or equal to 16" apart and no farther than 8" from the end of the batt.
- When batt thickness exceeds the depth of the roof framing members, full-width batts must be used to fit snugly and allow batts to expand beyond the framing members. Full coverage of the top chord framing members by insulation is recommended as best practice but is not required.

Figure 3-24: Details of Option B Assembly

Source: California Energy Commission

Figure 3--25: Placement of Insulation Below the Roof Deck

Source: California Energy Commission

When insulation is installed below the roof deck to meet the prescriptive requirements of Option B, a radiant barrier is not required. However, a draped radiant barrier may be installed to receive performance credit.

Vapor Retarders (Option B). Attic vapor retarders are not required by the Energy Code in most climates when using spray foam, blown-in insulation, or unfaced batts, and when sufficient attic ventilation is maintained. Although not required, the use of vapor retarders can provide additional security against possible moisture buildup in attic and framed assemblies. In climate zones 14 and 16, a Class I or Class II vapor retarder must

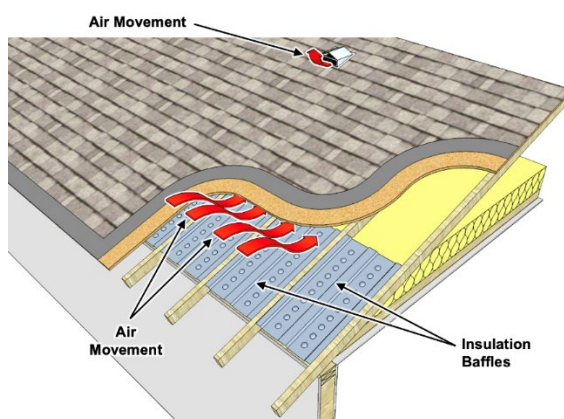
be used to manage moisture¹ as stated in California Building Code (CBC), Title 24, Part 2.5, Section R806.2.

Attic Ventilation (Options B and C)

Proper attic ventilation occurs at two points at the roof: the soffit (or eave) vents and the ridge (or eyebrow) vents. Ridge or eyebrow venting must be maintained, as shown in Figure 3-26.

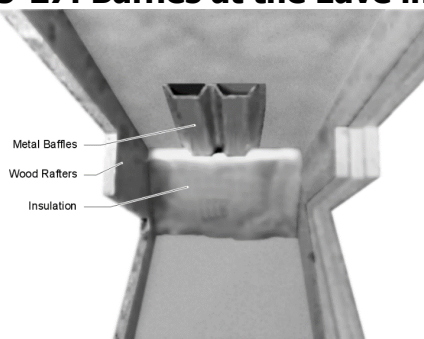
When installing insulation below the roof deck, vent baffles and insulation barriers should be used to maintain proper ventilation space. Proper airflow through the space helps remove moisture and prevents any associated issues.

Figure 3-26: Insulation Air Baffles



Source: Building Science Corporation

Figure 3-27: Baffles at the Eave in Attics



Source: California Energy Commission

Where ceiling insulation is installed next to eave or soffit vents, a rigid baffle should be installed at the top plate to direct ventilation air up and over the ceiling insulation. (See Figure 3-27.) The baffle should extend beyond the height of the ceiling insulation and

. 1 Insulation Contractors Association of America. (2004). Technical Bulletin No. 6 Use of Vapor Retarders.

should have sufficient clearance between the baffle and roof deck at the top. There are several acceptable methods for maintaining ventilation air, including preformed baffles made of either cardboard or plastic. In some cases, plywood or rigid foam baffles are used.

The California Building Code (CBC) requires a minimum vent area to be provided in roofs with attics, including enclosed rafter roofs creating cathedral or vaulted ceilings. Check with the local building jurisdiction to determine which of the two CBC ventilation requirements are to be followed:

1. CBC, Title 24, Part 2, Vol. 1, Section 1202.2 requires that the net-free ventilating area shall not be less than 1/300 of the area of the space ventilated.
2. CBC, Title 24, Part 2.5, Section R806.2 requires that the net-free ventilating area shall not be less than 1/150 of the area of the space ventilated. This ratio may be reduced to 1/300 if a ceiling vapor retarder is installed in climate zones 14 and 16. If meeting Option 1 above, a minimum of 40 percent and not more than 50 percent of the vents must be located in the upper portion of the space being ventilated at least 3 feet above the eave or cornice vents.

Insulation shall not block the free flow of air, and a minimum 1-inch air space shall be provided between the insulation and the roof sheathing and at the location of the vent.

Ventilated openings are covered with corrosion-resistant wire cloth screening or similar mesh material. When part of the vent area is blocked by meshes or louvers, the resulting “net-free area” of the vent must be considered to determine if ventilation requirements are met.

Many jurisdictions in California are covered by Wildland Urban Interface (WUI) regulations where specific requirements for construction materials must be used to improve fire resistance for the building. These regulations require special vents that are expressly tested to resist the intrusion of flames and burning embers. Check with the building department to ensure compliance with local codes.

Example 3--20: Installation Doesn't Match Compliant Design Option

Question: A newly constructed building project in climate zone 12 with HVAC ducts in the attic was designed to meet the prescriptive requirements for below roof deck and ceiling insulation. Due to miscommunication amongst the team, the roof deck insulation was not installed, and R-49 ceiling insulation was installed instead. Does this project still comply?

Answer: This project no longer meets the prescriptive requirements and must follow the performance approach. For future projects, clearly communicating the project expectations to all team members early in the construction process is the key to succeeding at this design strategy. Having a project initiation meeting with all subcontractors and team members is a best practice, at least for the first few projects, until the entire team is aware of the design needs.

Note: If the design was changed so that the roof deck has a radiant barrier and the HVAC equipment and ducts are verified to be in conditioned space, the altered design will meet the prescriptive requirements under Option C.

Note for Contractors/Installers: Tips for Successfully Implementing the High Performance Attics Requirements

- ✓ Commit to a compliance strategy early in the building design process.
- ✓ Have a kick-off meeting with builder, subcontractor, designer, energy consultant, and HERS Rater to set expectations and express the value of the design.
- ✓ Communicate strategy and schedule to subcontractors and other team members early.
- ✓ Include insulation specifications according to the CF1R on the building plans.
- ✓ Insulation contractor will install insulation below roof deck (ideally at the same time as ceiling insulation).
- ✓ All relevant subcontractors must be aware of where the air barrier is located and be conscious of where they make penetrations, especially if designing for verified ducts in conditioned space or reduced building envelope leakage.

Duct and Air Handlers Located in Conditioned Space Option C. Allows a project to place and verify that ducts are located in conditioned space instead of installing insulation at the roof deck. If complying with this option, ceiling and duct insulation must be installed at the values specified in Table 150.1-A for Option C, and a radiant barrier is required in most climate zones.

- **HERS Verification (Option C).** Simply locating ducts in conditioned space does not qualify for this requirement; a HERS Rater must test and verify for low leakage ducts within conditioned space and that the ducts are insulated to a level required in Table 150.1-A of the Energy Code.
- **Note for Architects/Designers:** Design strategies that can be used to prescriptively comply with Option C include dropped ceilings (dropped soffit), plenum or scissor truss to create a conditioned plenum box, and open-web floor truss. The key is that the ducts and equipment are placed within the air barrier of the building. Locating ducts within an unvented attic does not meet Option C requirements.
- **Ceiling Insulation (Options B and C).** Insulation coverage should extend far enough to the outside walls to cover the bottom chord of the truss. However, insulation should not block eave vents in attics because the flow of air through the attic space helps remove moisture that can build up in the attic and condense on the underside of the roof deck. This can cause structural damage and reduce the effectiveness of the insulation.

Based on area-weighted averaging, ceiling insulation may be tapered near the eave, but it must be applied at a rate to cover the entire ceiling at the specified level. An elevated truss is not required but may be desirable in some applications.

3.5.4 Wall Insulation

3.5.4.1 Mandatory Requirements §150.0(c)

- **2x4 inch wood-framed walls above grade.** Shall have a U-factor not exceeding U-0.102. In a wood-framed wall, this requirement is met with at least R-13 insulation installed in the cavities between framing members.
- **2x6 inch or greater wood-framed walls above grade.** Shall have a U-factor not exceeding 0.071. In a wood-framed wall, this requirement is met with at least R-20 insulation installed in the cavities between framing members.

Masonry walls above grade. Must be insulated to meet the prescriptive requirements in Table 150.1-A for mass walls.

All other wall types above grade. Must meet a maximum U-factor of U-0.102.

Demising partitions and knee walls. Demising and knee walls must meet or exceed minimum insulation requirements listed above, depending on wall type.

Exceptions: There are several cases where the mandatory requirements for wall insulation do not apply or apply in a special way. For best practice, the following should be implemented:

1. The mandatory requirements apply to framed foundation walls of heated basements or heated crawl spaces that are located above grade, but not to the portion that is located below grade.
2. For additions to existing buildings, existing wood-framed walls that are not being altered and are already insulated to a U-factor of 0.110 or lower, or that have existing R-11 insulation need not comply with the mandatory R-13 wall insulation. For more on additions see Chapter 9.
3. Rim joists between floors of a multistory building are deemed to comply with these mandatory requirements if they have R-13 insulation installed on the inside of the rim joist and are properly installed between intersecting joist members.

Demising Partitions and Knee Walls

Demising partitions and knee walls are not required to meet the prescriptive package requirements. Demising partitions and knee walls shall meet the mandatory minimum wall insulation requirements from §150.0(c).

3.5.4.2 Prescriptive Requirements (Table 150.1-A)

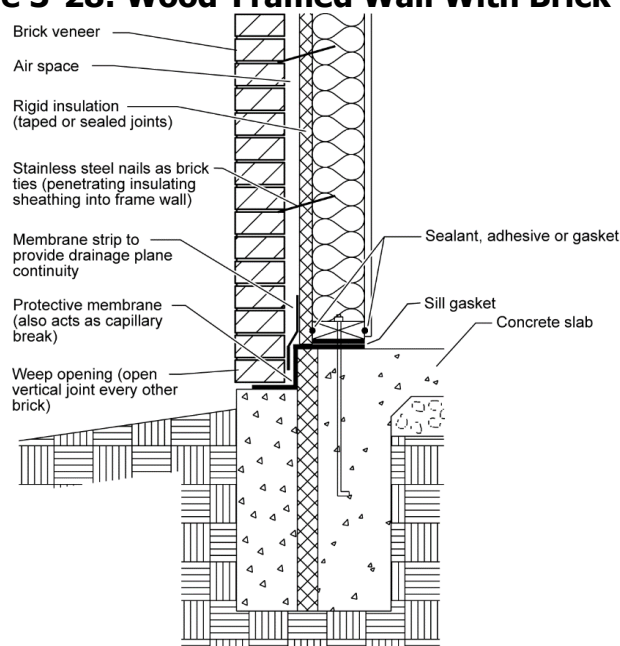
1. Framed Walls

The prescriptive requirements in Table 150.1-A call for a U-factor of 0.048 in climate zones 1-5 and 8-16, and a U-factor of 0.065 in climate zones 6 and 7.

The designer may choose any wall construction from Reference Appendices, Joint Appendix JA4 (Tables 4.3.1 and 4.3.4) that has a U-factor equal to or less than 0.048 or 0.065, depending on the climate zone.

Wood Frame. JA4 Table 4.3.4 shows that a 2x6 wood-framed wall at 16-inches-on-center can achieve a U-factor of 0.048 with R-21 batt insulation in the cavity and R-5 exterior insulation.

Figure 3-28: Wood-Framed Wall With Brick Veneer



Source: California Energy Commission

Some examples of various wood-framed wall assemblies, associated construction, and U-values are provided in Table 3-11.

Table 3-11: Examples of Wood-Framed Wall Assemblies and U-Factors, Assuming Gypsum Board Interior

Stud (16" oc)	Cavity Insulation	Cavity Insulation Type	Exterior Insulation	U-Factor
2x4	R15	High density batt	R4	0.065
2x4	R13	Open-cell spray foam (ocSPF)	R5	0.064
2x4	R15	High density batt	R8	0.050

Stud (16" oc)	Cavity Insulation	Cavity Insulation Type	Exterior Insulation	U-Factor
2x6	R21	Loose-fill cellulose or high density batt	R4	0.051
2x6	R19	Low density batt	R5	0.051
2x6	R31	Closed-cell spray foam (ccSPF)	R2	0.049
2x6	R23	High density batt or mineral wool	R4	0.049
2x6	R21	Loose-fill cellulose or high density batt	R5	0.048
2x6	R19	Low density batt	R6	0.048
2x6	R23	High density bat or mineral wool	R5	0.047

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

Calculating U-factors. U-factors can also be calculated by building the construction assembly in Commission-approved compliance software, including the inside finish, sheathing, cavity insulation, and exterior finish. Find approved compliance software here:

http://www.energy.ca.gov/title24/2022standards/2022_computer_prog_list.html.

Example 3-21: Prescriptive or Performance Approach for Wall Assembly?

Question: A new single-family house will have 2x6 framed walls with R-21 cavity insulation and R-5 continuous rigid insulation on the outside. Can this building comply with the Energy Code using either the prescriptive or performance approach?

Answer: If the house has wood framing, the assembly U-factor would be U-0.048 as per Reference Appendices, Joint Appendix JA4 Table 4.3.1. This U-factor prescriptively complies with the prescriptive U-factor requirements in all climate zones, and the building would not need to use the performance approach. If the house has metal framing, the assembly U-factor would be U-0.083 as per JA4 Table 4.3.4. This U-factor exceeds the maximum U-factor allowed in the prescriptive package and exceeds the mandatory maximum (U-0.071). The building would not comply regardless of the approach method used.

Example 3-22: Wall Assembly Not Found in Joint Appendix JA4

Question 1: For a new wall, if 2 inches of medium-density, closed-cell spray polyurethane foam (ccSPF) is used in combination with R-13 batt insulation in the cavity of a 2x6 wood framed wall with 16" on center spacing, without continuous insulation added, what is the total U-factor for the wall assembly?

Answer 1: Medium-density ccSPF is given a default value of R-5.8 per inch, as per Reference Appendices, Joint Appendix JA4 Table 4.1.7. When 2 inches of ccSPF is added to R-13 batt insulation, the total cavity insulation is rounded to R-25. The assembly U-factor was calculated to be 0.065 using Commission- approved compliance software:

Question 2: Does this assembly meet prescriptive compliance requirements in climate zones 6 and 7?

Answer 2: Yes. The assembly does meet the minimum mandatory wall insulation U-factor requirement of 0.071, as well as the prescriptive U-factor requirement of 0.065 in climate zones 6 and 7.

*CBECC-Res Software Wall Assembly Construction
showing U-0.065 Assembly*

The screenshot displays the 'Construction Data' tab in the CBECC-Res software. The 'Currently Active Construction' is set to 'Exterior Wall Cons'. The 'Construction Name' is 'Exterior Wall Cons', 'Can Assign To' is 'Exterior Walls', and 'Construction Type' is 'Wood Framed Wall'. The 'Construction Layers (inside to outside)' are defined in two columns: 'Cavity Path' and 'Frame Path'. The 'Cavity Path' layers are: Inside Finish (Gypsum Board), Sheathing / Insulation (- no sheathing/insul. -), Cavity / Frame (R 25), Sheathing / Insulation (- no sheathing/insul. -), and Exterior Finish (- select finish -). The 'Frame Path' layers are: Inside Finish (Gypsum Board), Sheathing / Insulation (- no sheathing/insul. -), Cavity / Frame (2x6 @ 16 in. O.C.), Sheathing / Insulation (- no sheathing/insul. -), and Exterior Finish (- select finish -). There are checkboxes for 'Non-Standard Spray Foam in Cavity' and 'Specify Non-std Framing Factor', both of which are unchecked. At the bottom, the 'Winter Design U-value' is calculated as 0.065 Btu/h-ft²-°F, with a note that it meets the maximum code U-value of 0.065.

Question 3: How about in other climate zones?

Answer 3: No. The assembly does not meet the prescriptive compliance U-factor requirement of 0.048 in climate zones 1-5 and 8-16 for single-family homes. To meet the prescriptive requirement for those climate zones, other wall assemblies may be used, and/or advanced wall system (AWS) techniques may be used to reduce the framing factor. Alternatively, the project may be shown to comply with the Energy Code using the performance approach. For more on the performance approach, see Section 3.6

2. Mass Walls

- **Location of Insulation.** The prescriptive requirements have separate criteria for mass walls with interior insulation and mass walls with exterior insulation. "Interior"

denotes that insulation is installed on the interior surface of the mass wall, and “exterior” denotes that insulation is installed on the exterior surface of the mass wall. Mass walls with insulation applied in locations other than directly to the interior or exterior, such as concrete sandwich panels, must meet the requirements for mass walls with exterior insulation. Mass walls with insulation applied to both the interior and exterior, such as insulated concrete forms (ICF), must meet the requirements for mass walls with interior insulation. Placement of insulation on mass walls will affect the thermal mass properties of a building. When the prescriptive compliance approach is used, the continuous insulation must be installed integral with or on the exterior or interior of the mass wall.

Calculating the U-Factor. To calculate the effective U-factor of a furred wall using the tables in Reference Appendices, Joint Appendix JA4:

1. Select a U-factor from JA4 Table 4.3.5 (Hollow Unit Masonry) or 4.3.6 (Solid Unit Masonry or Concrete) consistent with the type of wall.
2. Select the appropriate effective R-value for interior or exterior insulation layers from JA4 Table 4.3.14.
3. Use Equation 4-1, and the values selected, to calculate the U-factor of the construction assembly with the continuous insulation.
4. Compare the U-factor; it must be equal to or greater than the mass prescriptive U-factor from the Energy Code Table 150.1-A to comply.

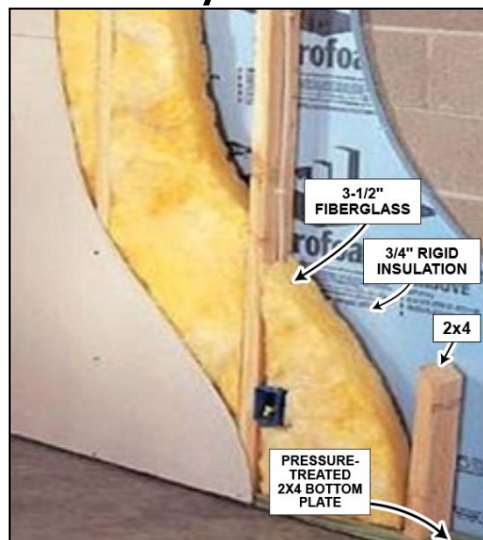
Note for Architects/Designers: The U-factor of furred concrete or masonry walls also can be determined by building the construction assembly in Commission-approved compliance software.

- **Compliance and Enforcement for Insulation Installation in Framed Assemblies.**
- Documentation of insulation R-values and assembly U-factors includes product data sheets, manufacturer specifications and installation guidelines, insulation product and assembly testing information, and U-factor calculations following the procedures specified in Reference Appendices, Joint Appendix JA4 or from results of approved performance compliance computer software.
- The plans examiner should verify that the insulation R-value for walls (cavity and/or continuous) on the CF1R document is specified on the building plans and compliant with Table 150.1-A.
- The building inspector should verify the installed wall insulation meets or exceeds the R-value on the CF1R document.

Batt and loose fill insulation should fill the wall cavity evenly. If kraft or foil-faced insulation is used, it should be installed per manufacturer recommendations to minimize air leakage and avoid sagging of the insulation.

Wall insulation should extend into the perimeter floor joist (rim joist) cavities along the same plane as the wall. If a vapor retarder is required, it must be installed on the conditioned space side of the framing.

Figure 3-29: Masonry Wall with Furring Details



Source: California Energy Commission

Note for Building Inspectors: Because it is difficult to inspect wall insulation behind tub and shower enclosures after the enclosures are installed, insulation of these wall sections should be inspected during the framing inspection.

Example 3--23: Minimum Insulation for Block Walls

Question: Do new residential buildings or additions consisting of block walls (for example, converting a garage into living space) need to comply with the R-13 minimum wall insulation requirement? If not, what insulation R-value do they need?

Answer: Block walls are considered masonry walls, and according to §150.0(c)3, the wall must have a U-factor not exceeding that required in Tables 150.1-A.

3.5.5 Raised-Floor Insulation §150.0(d)

3.5.5.1 Mandatory Requirements

Wood-framed floors over unconditioned space, regardless of whether there is a crawlspace, must have at least R-19 insulation installed between framing members, or the construction must have a U-factor of 0.037 or less. The equivalent U-factor is based on R-19 insulation in a 2x6, 16 inch on center wood-framed floor with a crawlspace.

Other types of raised floors, except for concrete raised floors (concrete raised floors do not have a mandatory requirement but do have a prescriptive requirement) must also meet the maximum U-factor. In all cases, some areas of the floor can have a U-

factor greater than the requirement as long as other areas have a U-factor that is lower than the requirement and the area-weighted average U-factor is less than that described above.

Raised slab floors with radiant heat (heated slab floors) must meet special insulation requirements that are described in Chapter 4 of this manual.

Note for Contractors/Installers: When a controlled ventilated or an unvented crawlspace is used, raised-floor insulation is not required, although a vapor retarder is required over the ground, and the foundation walls must be insulated.

3.5.5.2 Prescriptive Requirements

The prescriptive requirements differ for concrete raised floors and wood-framed floors. While the requirements for framed floors are the same in all climate zones, the requirements for concrete raised floors differ.

Framed Raised Floors. Table 150.1-A (prescriptive requirements) call for a minimum of R-19 insulation installed between wood framing or a maximum area-weighted average U-factor of 0.037 for framed raised floors in all climate zones. The requirement may be satisfied by installing the specified amount of insulation in a wood-framed floor or by meeting an equivalent U-factor. U-factors for raised floor assemblies are listed in Reference Appendices, Joint Appendix JA4.4.

Table 3-12: Wood-Framed Raised Floor Constructions Meeting Prescriptive Requirements

Insulation R-Value	Crawlspace?	Reference Joint Appendix JA4 Construction and Table Cell Entry	Equivalent U-Factor
R-19	No	4.4.2 A4	0.049
R-19	Yes	4.4.1 A4	0.037

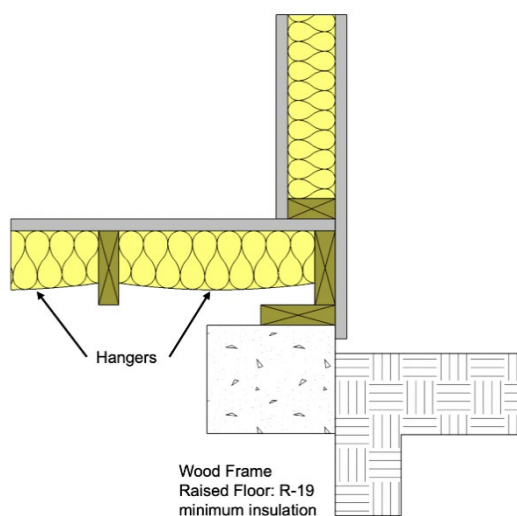
Source: California Energy Commission

Concrete Raised Floors. Insulation requirements for concrete raised floors differ by climate zone, summarized in Table 3-13.

Table 3-13: Insulation Requirements for Concrete Raised Floors per Table 150.1-A

Climate Zone	1,2,11,13,14,16	12,15	3-10
U-Factor	≤ 0.092	≤ 0.138	≤ 0.269
R-Value of Continuous Insulation	$\geq R-8$	$\geq R-4$	No Req.

Source: California Energy Commission

Figure 3-30: Raised Floor Insulation

Source: California Energy Commission

- **Installation.** Floor insulation should be installed in direct contact with the subfloor so that there is no air space between the insulation and the floor. Support is needed to prevent the insulation from falling, sagging, or deteriorating.
- Options for support include netting stapled to the underside of floor joists, insulation hangers running perpendicular to the joists, or other suitable means. Insulation hangers should be spaced at 18 inches or less before rolling out the insulation. See Figure 3-30. Insulation hangers are heavy wires up to 48 inches long with pointed ends, which provide positive wood penetration. Netting or mesh should be nailed or stapled to the underside of the joists. Floor insulation should not cover foundation vents.

3.5.6 Slab Insulation

3.5.6.1 Mandatory Requirements §150.0(f)

Slab Insulation Products

The mandatory requirements state that the insulation material must be suitable for the application. Insulation material in direct contact with soil, such as perimeter insulation, must have a water absorption rate no greater than 0.3 percent when tested in accordance with ASTM C272 Test Method A, 24-Hour Immersion, and a vapor permeance no greater than 2.0 perm/inch when tested in accordance with ASTM E96.

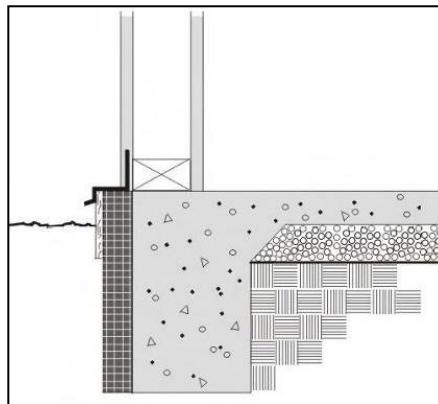
The insulation must be protected from physical and UV degradation by either installing a water-resistant protection board, extending sheet metal flashing below grade, choosing an insulation product that has a hard durable surface on one side, or by other suitable means.

The top of the insulation must be protected with a rigid material to prevent intrusion of insects into the building foundation.

A common location for the slab insulation is on the foundation perimeter (Figure 3-31). Insulation that extends downward to the top of the footing is acceptable. Otherwise, the insulation must extend downward from the level of the top of the slab, down 16 inches (40 cm) or to the frost line, whichever is greater.

For below-grade slabs, vertical insulation shall be extended from the top of the foundation wall to the bottom of the foundation (or the top of the footing) or to the frost line, whichever is greater.

Figure 3-31: Perimeter Slab Insulation



Source: California Energy Commission

Heated Slab Floor Insulation §110.8(g)

Heated slab-on-grade floors must be insulated according to the requirements in Table 110.8-A and Table 3-14.

One option is to install the insulation between the heated slab and foundation wall. In this case, insulation must extend downward to the top of the footing and then extend horizontally inward four feet toward the center of the slab. R-5 vertical insulation is required in all climates except climate zone 16, which requires R-10 of vertical insulation and R-7 horizontal insulation.

Table 3-14: Slab Insulation Requirements for Heated Slab Floors

Insulation Location	Insulation Orientation	Installation Requirements	Climate Zone	Insulation R-Value
Outside edge of heated slab, either inside or outside the foundation wall	Vertical	From the level of the top of the slab, down 16 inches or to the frost line, whichever is greater. Insulation may stop at the top of the footing, where this is less than the required depth. For below-	1 – 15	5
			16	10

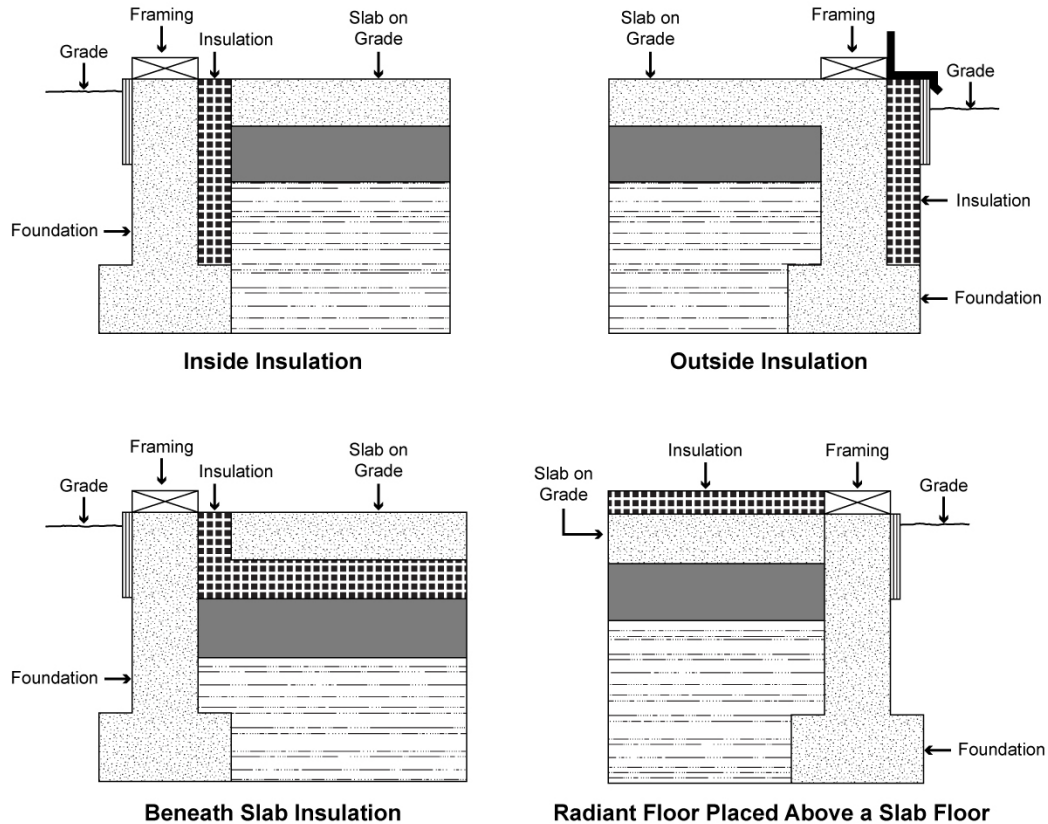
Insulation Location	Insulation Orientation	Installation Requirements	Climate Zone	Insulation R-Value
		grade slabs, vertical insulation shall be extended from the top of the foundation wall to the bottom of the foundation (or the top of the footing) or to the frost line, whichever is greater.		
Between heated slab and outside foundation wall	Vertical and Horizontal	Vertical insulation from top of slab at inside edge of outside wall down to the top of the horizontal insulation. Horizontal insulation from the outside edge of the vertical insulation extending 4 feet toward the center of the slab in a direction normal to the outside of the building in plain view.	1 – 15 16	5 10 vertical and 7 horizontal

Source: California Energy Commission

3.5.6.2 Prescriptive Requirements

Table 150.1-A of the Energy Code requires slab insulation only in climate zone 16 for unheated slabs. All heated slabs must meet mandatory insulation requirements in §110.8(g).

For unheated slabs in climate zone 16, a minimum of R-7 slab-edge insulation or a maximum U-factor of 0.58 must be achieved. The insulation must be installed to a minimum depth of 16 inches or to the bottom of the footing, whichever is less. The depth is measured from the top of the insulation, as near the top of slab as practical, to the bottom edge of the insulation. See Figure 3-32.

Figure 3-32: Allowed Slab Edge Insulation Placement

Source: California Energy Commission

Note for Contractors//Installers: Perimeter insulation is not required along the slab edge between conditioned space and the concrete slab of an attached unconditioned enclosed space such as a garage, covered porch, or covered patio. Neither would it be practical or necessary to insulate concrete steps attached to the outside slab edge.

Example 3--24: Heated Slab Insulation

Question: What are the slab edge insulation requirements for a hydronic-heating system with the hot water pipes in the slab?

Answer: The requirements for insulation of heated slabs can be found in §110.8(g) of the Energy Code and are described in Section 3.5.6.1 of this manual. The material and installation specifications are as follows:

1. Insulation values as shown in Table 110.8-A of the Energy Code
 2. Protection from physical damage and UV light deterioration
 3. Water absorption rate no greater than 0.3 percent (ASTM C272)
 4. Water vapor permeance no greater than 2.0 perm/inch (ASTM E96)
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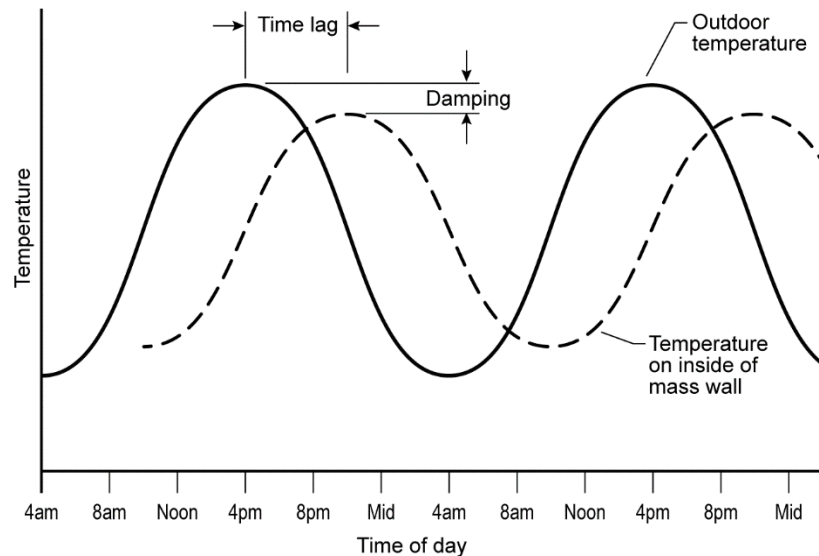
3.5.7 Thermal Mass

Thermal mass consists of exposed tile floors over concrete, mass walls such as stone or brick, and other heavy elements within the building envelope that stabilizes indoor temperatures. Thermal mass helps temper interior temperature, storing heat or cooling for later use. In California's Central Valley and desert climates, the summer temperature range between night and day can be 30°F or more, and thermal mass can be an effective strategy to reduce daytime cooling loads.

Mass walls typically fall into two categories:

- **Masonry.** Masonry includes clay and concrete units, which may be solid or hollow, and glazed or unglazed. Other masonry unit types include cast stone and calcium silicate units. Concrete masonry units (CMU) are made from a mixture of Portland cement and aggregates under controlled conditions. Concrete masonry units can be manufactured in different sizes and with a variety of face textures.
- **Concrete and concrete sandwich panels.** Concrete and concrete sandwich panels typically use a precast form by casting concrete in a reusable mold or "form" that is then cured in a controlled environment, transported to the construction site, and lifted into place. Precast stone is distinguished from precast concrete by using a fine aggregate in the mixture, giving the appearance of naturally occurring rock or stone.

When thermal mass exists in exterior walls, it stabilizes temperatures in two ways. First, there is a time delay between when the outside temperature of the wall reaches its peak and when the inside of the wall reaches its peak. For an 8-inch to 12-inch concrete wall, this time delay is between 6 to 10 hours. Second, there is a dampening effect whereby the temperature range inside the house is less than the temperature range outside the house. These effects are illustrated in the Figure 3-33.

Figure 3-33: Thermal Mass Performance

Source: California Energy Commission

When the performance method is used, credit is offered for increasing thermal mass in buildings. This procedure is automated in Energy Commission-approved computer compliance software. See Section 3.6 for the performance method.

3.5.8 Quality Insulation Installation (QII) RA 3.5

Prescriptive Requirements (Table 150.1-A)

The prescriptive requirements shown in Table 150.1-A calls for QII in all climate zones for newly constructed buildings and additions greater than 700 square feet.

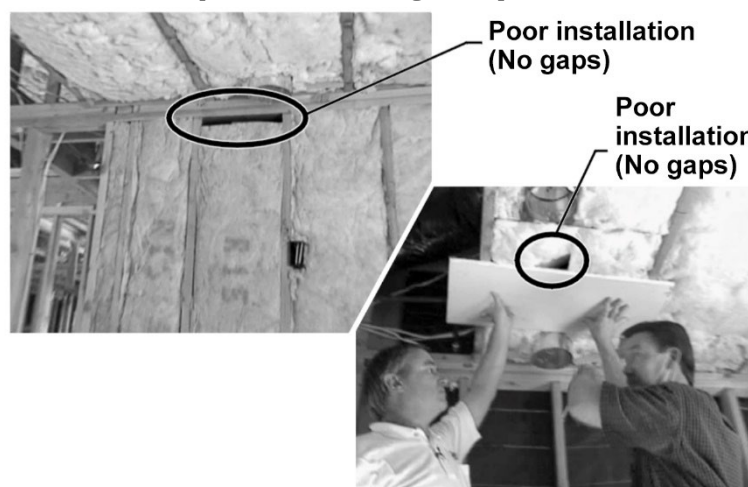
All insulation shall be installed properly throughout the building. A third-party HERS Rater is required to verify the integrity of the installed insulation. The installer shall provide evidence to the HERS Rater using compliance documentation that all insulation specified is installed to meet specified R-values and assembly U-factors.

To meet QII, two primary installation criteria must be adhered to, and they both must be field-verified by a HERS Rater. They include air sealing of the building enclosure (including walls, ceiling/roof, and floors), as well as proper installation of insulation. Refer to Reference Appendices, Residential Appendix RA3.5 for more details.

Many residential insulation installations have flaws that degrade thermal performance. Four problems are generally responsible for this degradation:

1. There is an inadequate air barrier in the building envelope or holes and gaps within the air barrier system that inhibit the ability to limit air leakage.
2. Insulation is not in contact with the air barrier, creating air spaces that short-circuit the thermal break of the insulation when the air barrier is not limiting air leakage properly.
3. The insulation has voids or gaps, resulting in portions of the construction assembly that are not properly insulated and, therefore, have less thermal resistance than other portions of the assembly (Figure 3-34).
4. The insulation is compressed, creating a gap near the air barrier and/or reducing the thickness of the insulation.

Figure 3--34: Examples of Poor Quality Insulation Installation



QII requires third-party HERS inspection to verify that an air barrier and insulation are installed correctly to eliminate or reduce common problems associated with poor installation. Guidance for QII is provided in Reference Appendices, Residential Appendix RA3.5. QII applies to framed and nonframed assemblies. Residential construction may incorporate multiple frame types, for example, using a combination of nonframed walls with a framed roof/ceiling. Likewise, multiple insulation materials often are used.

Framed Assemblies

Framed assemblies include wood and steel construction insulated with batts of mineral fiber, mineral and natural wool, or cellulose; loose-fill insulation of mineral fiber, mineral and natural wool, cellulose, or spray polyurethane foam (SPF). Rigid board insulation may be used on the exterior or interior of framed or nonframed assemblies.

Nonframed Assemblies

Nonframed assemblies include structural insulated panels (SIP), insulated concrete forms (ICF), and mass walls of masonry, concrete and concrete sandwich panels, log walls, and straw bale.

Note for Contractors/Installers: Tips for Implementing QII

Applies to all Insulation	QII applies to the whole building - roof/ceilings, walls, and floors - and requires field verification by a third-party HERS Rater.
Slab Edge Insulation	<ul style="list-style-type: none"> If slab edge insulation is installed, then the integrity of the slab edge insulation must also be field-verified in addition to the air barrier and insulation system for walls and the roof/ceiling.
Various Insulation Types	<ul style="list-style-type: none"> Combinations of insulation types (hybrid systems) are allowed.
Air Barriers	<ul style="list-style-type: none"> An air barrier shall be installed for the entire envelope. Air barrier must be verified prior to insulation being installed.
Additions	<ul style="list-style-type: none"> QII is prescriptively required for additions to existing buildings more than 700 square feet. Refer to Chapter 9 for additional information specific to additions.
Insulated Headers	<ul style="list-style-type: none"> Headers shall meet one of the following criteria for QII: <ol style="list-style-type: none"> Two-member header with insulation in between. The header and insulation must fill the wall cavity. There are prefabricated products available that meet this assembly. Example: a 2x4 wall with two 2x nominal headers, or a 2x6 wall with a 4x nominal header and a 2x nominal header. Insulation is required to fill the wall cavity and must be installed between the headers. Two-member header, less than the wall width, with insulation on the interior face. The header and insulation must fill the wall cavity. Example: a 2x6 wall with two 2x nominal headers. Insulation is required to fill the wall cavity and must be installed to the interior face of the wall. Single-member header, less than the wall width, with insulation on the interior face. The header and insulation must fill the wall cavity. Example: a 2x4 wall with a 3-1/8-inch-wide header, or 2x6 wall with a 4x nominal header. Insulation is

Applies to all Insulation	QII applies to the whole building - roof/ceilings, walls, and floors - and requires field verification by a third-party HERS Rater.
	<p>required to fill the wall cavity and must be installed to the interior face of the wall. Note: All single member window and door headers shall be insulated to a minimum of R-3 for a 2x4 framing, or equivalent width, and a minimum of R-5 for all other assemblies.</p> <p>d. Single-member header, same width as wall. The header must fill the wall cavity. Example: a 2x4 wall with a 4x nominal header or a 2x6 wall with a 6x nominal header. No additional insulation is required provided that the entire wall has at least R-2 continuous rigid insulation installed on the exterior.</p>
Panel Box Headers	<ul style="list-style-type: none"> Wood structural panel box headers may also be used as load-bearing headers in exterior wall construction, when built in accordance with California Residential Code (CRC) Figure R602.7.3 and Table R602.7.3.
Structural Bracing, Tie-Downs, Steel Structural Framing	<ul style="list-style-type: none"> Metal bracing, tie-downs, or steel structural framing can be used to connect to wood framing for structural or seismic purposes, and comply with QII if: <ul style="list-style-type: none"> a. Metal bracing, tie-downs, or steel structural framing is identified on the structural plans. b. Insulation is installed in a manner that minimizes the thermal bridging through the structural framing assembly. c. Insulation fills the entire cavity and/or adheres to all six sides and ends of structural assemblies that separate conditioned from unconditioned space. d. The structural portions of assemblies are airtight.

Source: California Energy Commission

- QII in the Compliance Modeling Software.** QII is not a mandatory requirement; therefore, when using the performance approach, QII may be traded off with other efficiency requirements. However, the compliance modeling software assumes QII and full insulation effectiveness in the standard design. The compliance modeling software automatically reduces the effectiveness of insulation for the proposed design in projects that do not pursue QII. The effect of a poorly installed air barrier system and envelope insulation results in higher wall heat loss and heat gain than standard R-value and U-factor calculations would indicate. Similar increases in heat loss and

heat gain are experienced for roof/ceilings where construction and installation flaws are present. The reduction in effectiveness reflects standard industry installation practices and allows for full insulation credit to be taken for HERS verified quality insulation installation.

3.5.8.1 Air Barrier RA3.5.2

An air barrier shall be installed enclosing the entire building. The air barrier must be installed in a continuous manner across all components of framed and nonframed envelope assemblies. The installer shall provide evidence with compliance documentation that the air barrier system meets one or more of the air barrier requirements. More detailed explanation is provided in Reference Appendices, Residential Appendix RA3.5. Documentation for the air barrier includes product data sheets and manufacturer specifications and installation guidelines.

Note for HERS Raters: For QII, a third-party HERS Rater is required to verify that the air barrier has been installed properly and is integral with the insulation being used throughout the building.

Note for Contractors/Installers: Continuous Air Barrier Requirements

A combination of interconnected materials and assemblies are joined and sealed together to provide a continuous barrier to air leakage through the building envelope separating conditioned from unconditioned space or adjoining conditioned spaces of different occupancies or uses. An air barrier must meet one of the following:

- a. Using materials that have an air permeance not exceeding 0.004 cfm/ft² under a pressure differential of 0.3 in. w.g. (1.57 psf) (0.02 L/s.m² at 75 pa) when tested in accordance with ASTM E2178.
- b. Using assemblies of materials and components that have an average air leakage not to exceed 0.04 cfm/ft² under a pressure differential of 0.3 in. w.g (1.57 psf) (0.2 L/s.m² at 75 pa) when tested in accordance with ASTM E2357, ASTM E1677, ASTM E1680 or ASTM E283.
- c. Testing the completed building and demonstrating that the air leakage rate of the building envelope does not exceed 0.40 cfm/ft² at a pressure differential of 0.3 in w.g. (1.57 psf) (2.0 L/s.m² at 75 pa) in accordance with ASTM E779 or an equivalent approved method.

The following materials meet the air permeance testing performance levels of 1 above. Manufacturers of these and other product types must provide a specification or product data sheet showing compliance to the ASTM testing requirements to be considered as an air barrier.

- Plywood – minimum 3/8 inch
- Oriented strand board – minimum 3/8 inches
- Extruded polystyrene insulation board – minimum 1/2 inch
- Foil-backed polyisocyanurate insulation board – minimum 1/2 inch
- Foil-backed urethane foam insulation – 1 inch
- Closed-cell spray polyurethane foam (ccSPF) with a minimum density of 2.0 pcf and a minimum thickness of 2.0 inches. Alternatively, ccSPF insulation shall be installed at a thickness that meets an air permeance no greater than 0.02 L/s-m² at 75 Pa pressure differential when tested in accordance with ASTM E2178 or ASTM E283.
- Open cell spray polyurethane (ocSPF) foam with a minimum density of 0.4 to 1.5 pcf and a minimum thickness of 5½ inches. Alternatively, ocSPF insulation shall be installed at a thickness that meets an air permeance no greater than 0.02 L/s-m² at 75 Pa pressure differential when tested in accordance with ASTM E2178 or ASTM E283.
- Exterior or interior gypsum board – minimum 1/2 inch
- Cement board – minimum 1/2 inch
- Built-up roofing membrane
- Modified bituminous roof membrane
- Particleboard – minimum 1/2 inch
- Fully adhered single-ply roof membrane
- Portland cement/sand parge, or gypsum plaster – minimum 5/8 inch
- Cast-in-place and precast concrete
- Fully grouted uninsulated and insulated concrete block masonry
- Sheet steel or aluminum

Materials and assemblies of materials that can demonstrate compliance with the air barrier testing requirements must be installed according to the manufacturer's instructions, and a HERS Rater shall verify the integrity of the installation.

3.6 Opaque Envelope in the Performance Approach

Some residential projects may not wish to use or do not meet the requirements for prescriptive compliance. The performance approach offers increased flexibility as well as compliance credits for certain assemblies, usually those requiring HERS verification. The designs described below are examples of residential envelope strategies that can be implemented under the performance approach. The proposed design used under the performance approach is compared to the standard design,

which is determined by the prescriptive requirements. Remember that when using the performance approach, all applicable mandatory requirements must still be met.

Advanced Assemblies. Common strategies for exceeding the minimum energy performance level set by the 2022 Energy Code include the use of better components such as:

- Higher insulation levels.
- More efficient fenestration.
- Reducing building infiltration.
- Use of cool roof products.
- Better framing techniques (such as the use of raised-heel trusses that accommodate more insulation).
- Reduced thermal bridging across framing members.
- Greater use of nonframed assemblies or panelized systems (such as SIPs and ICFs).
- More efficient heating, cooling, and water-heating equipment.

The performance approach encourages the use of energy-saving techniques for showing compliance with the Energy Code.

Advanced Building Design. The design of a building, floor plan, and site design layout all affect energy use. A passive design building uses elements of the building to heat and cool itself, in contrast to relying on mechanical systems to provide the thermal energy needs of the building. Passive solar strategies encompass several advanced high-performance envelope techniques, such as:

1. Carefully choosing the size, type, and placement of fenestration and shading.
2. Providing and controlling fresh air ventilation during the day and night.
3. Having internal and external thermal mass components that help store useful heat and cooling energy.
4. Having highly insulated envelope assemblies.
5. Using high performing roofing materials (cool roofs) and radiant barriers.
6. Having very low air leakage.

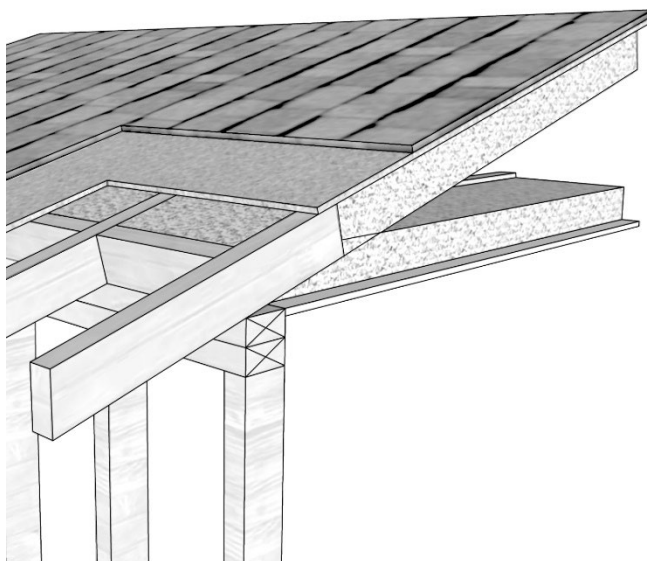
Some requirements designed as part of an advanced assembly system may require specific installation procedures or field verification and diagnostic testing to ensure proper performance. Field verification and diagnostic testing are ways to ensure that the energy efficiency features used in compliance calculations are realized as energy benefits to the occupants.

3.6.1 Unvented Attics

Attic ventilation is the traditional way of controlling temperature and moisture in an attic. In an unvented attic assembly, insulation is applied directly at the roofline of the building, either above or below the structural roof rafter. The roof system becomes part of the insulated building enclosure. For this case, the thermal boundary of the building results in an unvented attic space between the ceiling gypsum board and the insulated roof above (Figure 3-35).

In addition to meeting the mandatory minimum insulation requirements, the provisions of California Building Code (CBC), Title 24, Part 2.5, Section R806.5 must be met.

Figure 3-35: Unvented Attic Assembly with Insulation at the Ceiling and Between the Roof Rafters



Source: California Energy Commission

Check with the local building jurisdiction to determine its specific requirements for unvented attic conditions.

Combining this strategy with the additional design improvement of low air leakage for the rest of the building would achieve energy savings and compliance energy credit.

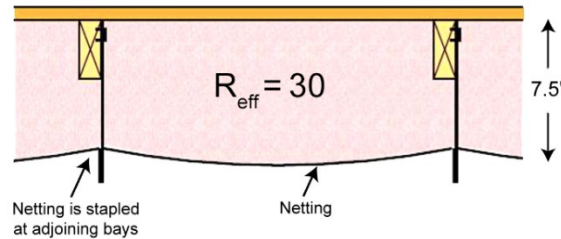
Furthermore, this design eliminates the need to seal or limit penetrations at the ceiling level, such as recessed cans, because the air and thermal boundary is now located at the roof deck.

3.6.1.1 Below-Roof Deck Netted Insulation in Unvented Attics

Alternative types of insulation can provide high R-value insulation below the roof deck in an unvented attic. One approach is a boxed netted system that is suspended from the top member of the truss, or top chord, to provide a fill depth that completely encloses the top chord, creating a uniform insulation layer of loose-fill fiberglass across the entire underside of the roof deck. This method can be done with common loose-fill insulation tools and equipment. See Figure 3-36 for details of this type of below-deck netted

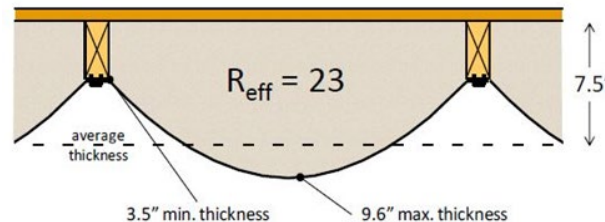
insulation. Draped netted insulation, another approach to below-deck insulation, results in a nonuniform insulation layer, created by leaving the truss chords exposed and leading to increased thermal bridging (Figure 3-37).

Figure 3-36: Box Netted Insulation



Source: Owens Corning

Figure 3-37: Draped Netted Insulation



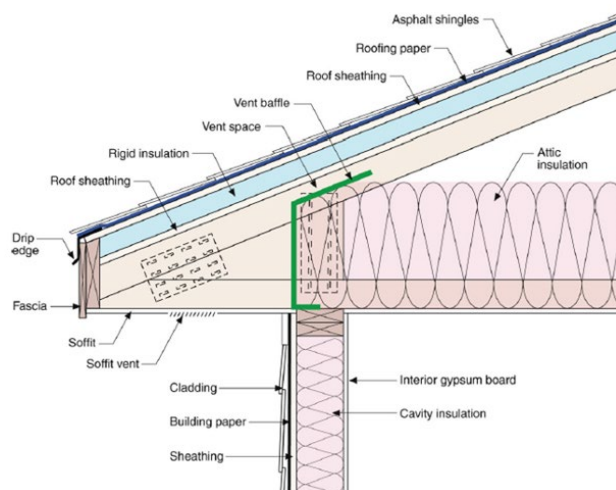
Source: Owens Corning

Gable Ends in Unvented Attics

In unvented attics, where insulation is applied directly to the underside of the roof deck, framing for gable ends that separate the unvented attic from the exterior or unconditioned space shall be insulated to meet or exceed the wall R-value of the adjacent exterior wall construction. The backside of air-permeable insulation exposed to the unconditioned attic space shall be completely covered with a continuous air barrier.

3.6.2 Above-Roof Deck Insulation

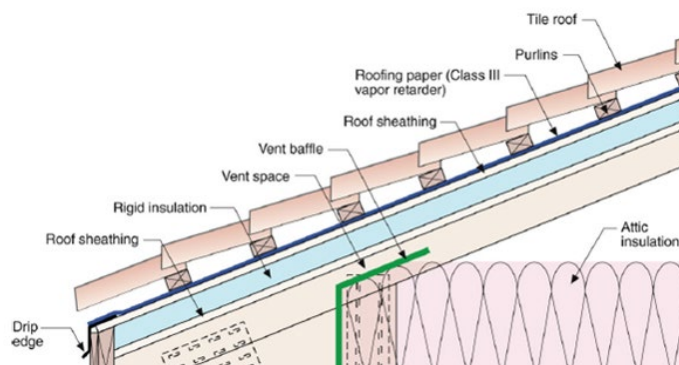
A layer of continuous rigid insulation above and in direct contact with the roof deck (sheathing) increases the thermal integrity of the roof system. Continuous above-roof deck insulation is suitable for use with either asphalt shingles or clay/concrete tiles. Required R-values for insulation installed above the roof deck are lower than R-values for insulation installed below the roof deck due to reduced thermal bridging when continuous insulation is applied directly above the roof deck. Further, an air space installed between the roof deck and the roofing tiles or shingles improves cooling of the roof assembly.

Figure 3-38: Detail of Above-Roof Deck Insulation

Source: Building Science Corporation

Note for HERS Raters: Check manufacturer's specifications for proper nail schedules (fastening patterns); this will change depending on the roof pitch, truss spacing, and roofing material.

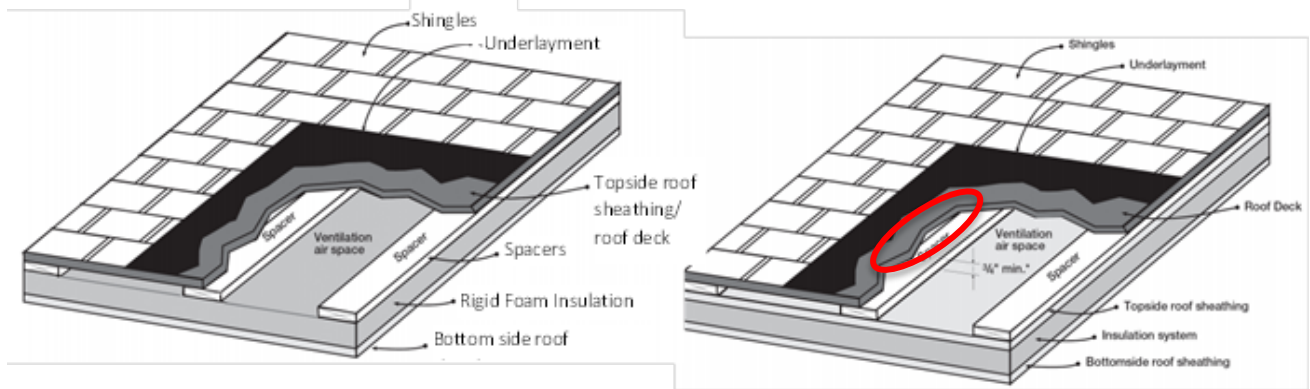
With concrete and clay tiles. Standard construction practice in California for concrete and clay tiles is to have an air gap between the tiles and roof deck because the tiles are installed over horizontal battens (or purlins). One option is to install continuous rigid insulation over the roof deck and a second layer of roof sheathing above the rigid insulation. If required by climate zone, a vapor retarder would be installed above the second sheathing layer to host the purlins with the tiles installed over them (Figure 3-39).

Figure 3-39: Battens (Purlins) Installed with Above-Roof Deck Insulation

Source: Building Science Corporation

With asphalt shingles. When installing asphalt shingles over above-roof deck insulation, it is best practice to ensure an air gap between the shingles and the top sheathing or insulation, as shown in Figure 3-40, to mitigate the effect of high temperatures that reduce the effective life of roofing products.

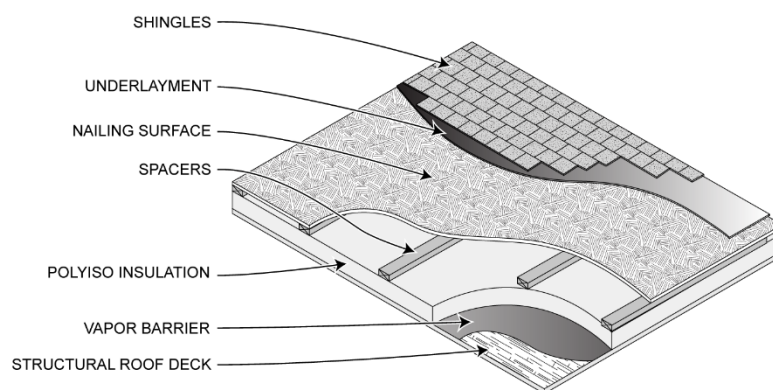
Figure 3--40: Above-Roof Deck Insulation and Air Spaces with and without A Second Layer of Roof Sheathing



Source: ARMA technical bulletin No. 211-RR-94

Spacers can be inserted above or below a second roof sheathing to provide roof deck ventilation and a nailable base for asphalt shingles (Figure 3-41). Prefabricated insulation products with spacers and top sheathing are available. Check manufacturers' and trade association websites for a list of products that provide an air space and nailable base.

Figure 3--41: Asphalt Shingles and Spacers Installed with Above-Roof Deck Insulation



Source: PIMA Tech Bulletin #106

Example 3-25: Two Layers of Rigid Foam Board Above-Roof Deck

Question: Can two layers of R-4 rigid foam board be installed as an equivalent performance to R8 rigid foam insulation above the roof deck? If so, are there best practices for installing the two layers of insulation?

Answer: Yes, installing two R-4 rigid foam board layers is equivalent in performance to R-8. To prevent water infiltration, it is best to stagger the horizontal and vertical joints of the two layers and take care to seal each joint properly.

Example 3--26: Roof Material Directly Over Rigid insulation

Question: A project plans to install R-6 rigid foam insulation above the roof deck with roofing material placed *directly* over the insulation. What are the best practices for installing the insulation?

Answer: Insulation can be installed directly on the roof deck with no air gap, but performance is improved if an air gap is installed between the rigid insulation and the roofing material by using spacers or battens (purlins). Products exist that combine insulation, spacers, and additional sheathing for nailing asphalt shingles. Check with insulation manufacturers for available products.

Example 3--27: Fire Ratings Required by CBC, Chapter 15

Question: Does a roof assembly using above-roof deck insulation meet Class A/B/C fire rating specifications, as determined by California Building Code (CBC), Chapter 15?

Answer: Application of above-roof deck insulation affects the fire rating classification of roof covering products. Roof covering products are rated to Class A/B/C based on the ASTM E108 (NFPA 256, UL790) test. Class A/B/C ratings are done with specific roof assemblies, and ratings are valid only when the installation is the same as the assembly as rated. Under current building code requirement, tile roof products installed directly over the roof deck or over purlins 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 ASTM E108. These materials include slate, clay, concrete roof tile, an exposed concrete roof deck, and ferrous and copper shingles; however, asphalt shingles are not covered under this category.

Insulation products, on the other hand, are subject to a different fire test from roof-covering products. The California Building Code and International Building Code (Section 2603 for Foam Plastic Insulation) require foam plastic insulation to be tested to demonstrate a flame-spread index of not more than 75 and a smoke-developed index of not more than 450 according to ASTM E84 (UL723). The requirements apply to roof insulation products, including XPS/polyiso/polyurethane above-deck insulation and SPF below-deck insulation products.

To ensure that insulated roof assemblies meet the proper fire rating classification, roof product manufacturers and insulation manufacturers must test and develop assemblies that meet the CBC testing specifications.

3.6.3 Insulated Roof Tiles

Insulated roof tile (IRT) is an option for improving the thermal performance of the roof assembly and lowering attic temperatures. IRT combines concrete or clay tiles with insulation as an integrated product (Figure 3-42). These tiles are lighter than typical roof tiles and have better thermal performance than traditional tiles due to the insulating core.

Figure 3-42: Insulated Concrete Tile

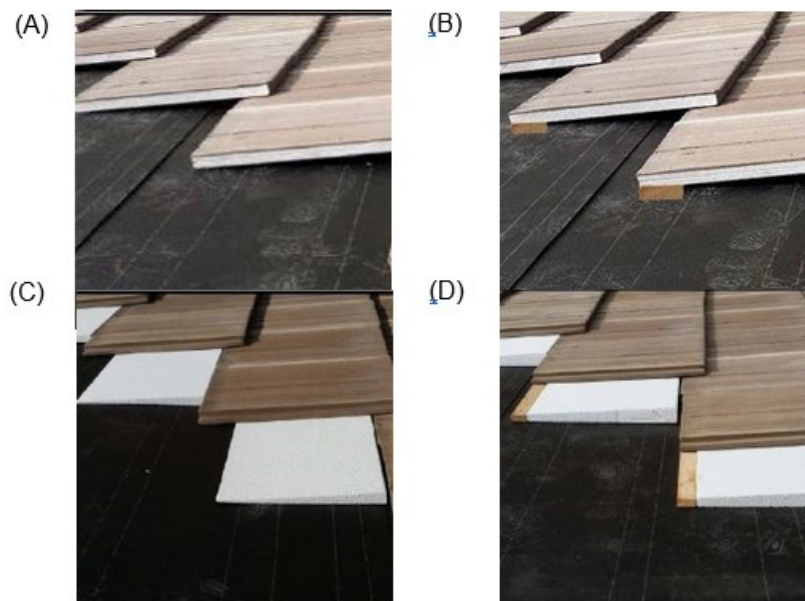
Source: Green Hybrid Roofing

IRT can reduce radiant losses and maintain warmer roof deck temperatures, thereby reducing the potential for condensation. Using one of the options below provides additional R-value when conventional ceiling insulation is installed.

Configurations A and B in Figure 3-43 can be installed without significant changes to conventional roof or attic design (such as fascia dimensions), and IRT can be used in both vented and unvented attic configurations.

Some IRT products are ASTM-rated for Class A fire rating (ASTM E108) and have CRRC certification for cool roof tiles in multiple colors. It is best practice to check with manufacturers about the U-factor and ASTM ratings for each IRT product. Manufacturers cite several advantages of the product, including the lightweight construction, faster installation than traditional roof tiles, less weight on the roof structure, and improved thermal performance.

Figure 3-43: Insulated Roof Tile (IRT) (A) Attached Directly to Roof Deck, (B) Attached to Batten, (C) Attached Directly to Roof Deck With Wedged Foam Filling Air Space, and (D) Attached to Battens With Wedged Foam Filling Air Space



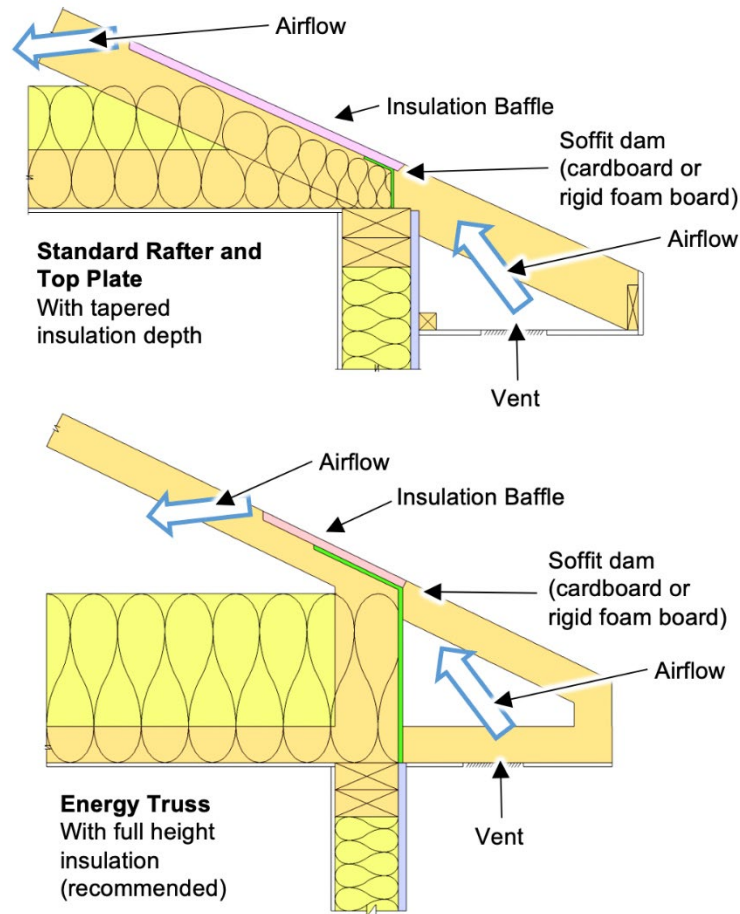
Source: Green Hybrid Roofing

3.6.4 Raised Heel, Extension Truss, or Energy Truss

- The use of an energy truss, also referred to as a raised heel or extension truss, allows full depth, uncompressed insulation at the ceiling to continue to the ceiling edge where the roof and ceiling meet. For this strategy, the roof truss is assembled with an additional vertical wood framed section at the point where the top and bottom truss chords meet. The vertical section raises the top chord and provides increased space that can be filled with insulation. See Figure 3-44 for details of a raised heel truss. Benefits of this strategy include:
 - Realizing the full R-value benefit of ceiling insulation.
 - Providing more space for mechanical systems located in the attic.

The 2022 CBECC-Res compliance software allows for the modeling of raised heel trusses and provides credit for the additional edge insulation.

Note for Contractors/Installers: Other methods to achieve a similar outcome include framing with rafters on raised top plate, or applying additional spray foam or rigid foam inside the perimeter of the attic.

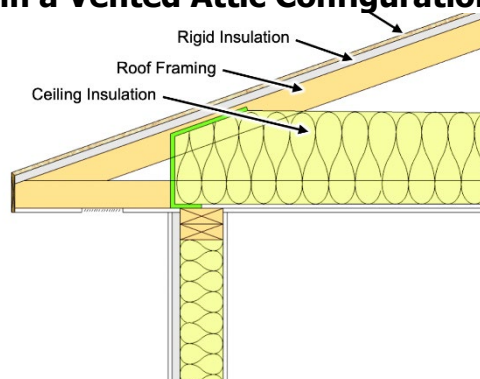
Figure 3-44: Standard Truss vs. Raised Heel Energy Truss

Source: California Energy Commission

3.6.5 Nail Base Insulation Panel

The nail base insulation panel is an above-roof deck insulation strategy that consists of exterior-facing OSB or other structural sheathing laminated to continuous rigid insulation, which is fastened directly to roof framing (Figure 3-45). This saves the time and expense of installing a structural sheathing layer above and below the rigid insulation. The nail base insulation panel creates a nailing surface for attaching roof cladding.

Figure 3-45: Nail Base Insulation Panel with Radiant Barrier Affixed to Trusses in a Vented Attic Configuration



Suitable for vented and unvented attic assemblies, the exposed underside of the rigid insulation is face with a radiant barrier that also provides an ignition/thermal barrier protection as required by code.

Source: California Energy Commission

Example 3-31: Area-Weighted Average Insulation Levels

Question: A computer method analysis shows that a new house requires R-19 ceiling insulation to comply using the performance approach, but the minimum mandatory insulation level for ceiling insulation is R-22. Which insulation level should be used?

Answer: The mandatory minimum insulation requirement is an area-weighted average U-factor. Some ceiling areas can have lower insulation, such as R-19, but other areas will need to have higher levels of insulation so that the area-weighted average U-factor is at least 0.043.

Example 3--28: Minimum Insulation Levels When Using Performance Approach

Question: A small addition to an existing house appears to comply using only R-15 ceiling insulation with the performance approach. Does this insulation level comply with the Energy Code?

Answer: No. R-15 would not be sufficient because the required minimum ceiling insulation level established by the mandatory requirements is R-22. However, R-15 could be used in limited areas, as follows:

- a. Attic roofs must have a weighted average U-factor of 0.043 or less for the entire ceiling/roof.
 - b. Cathedral or rafter roofs must have a weighted average U-factor of 0.054 or less for the entire ceiling/roof.
-

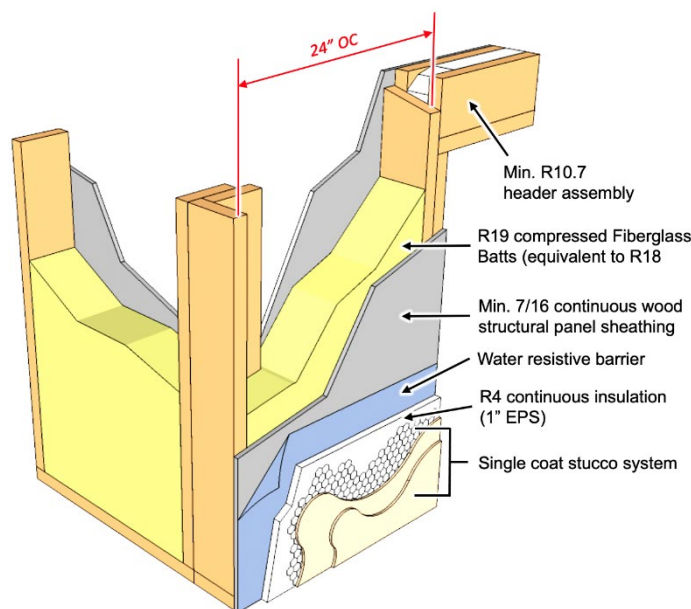
3.6.6 Advanced Wall Systems and Advanced Framing

Advanced wall systems (AWS), also known as optimum value engineering (OVE) or advanced framing, refer to a set of framing techniques and practices that minimize the amount of wood and labor necessary to build a structurally sound, safe, durable, and

energy-efficient building. AWS improves energy and resource efficiency while reducing first costs.

Reducing the amount of wood in wood-framed exterior walls improves energy efficiency through a reduced framing factor, allowing more insulation to be installed, and has greater resource efficiency for the materials being used. In addition, using fewer framing studs reduces the effects of thermal bridging and increases the amount of insulation in the wall, resulting in a more energy-efficient building envelope. The framing factor assumed for calculating the energy performance of a wood-framed 2x4 wall at 16-inches on center is 25 percent. When AWS is used, the framing factor is reduced to 17 percent, reflecting the improved energy performance of the advanced wall system.

Figure 3-46: Wood-Framed Wall, 2x6 @ 24" oc, AWF With Three-Stud corners



Source: California Energy Commission

Calculating Assembly U-Factors. Figure 3-46 depicts one AWS that achieves a U-factor of 0.048 with an exterior insulation of R-4, due to 24" stud spacing and R-13 header assemblies.

Table 3-15 lists the assembly components for the AWS in Figure 3-46.

These values were calculated using the parallel heat flow calculation method, documented in the *2009 ASHRAE Handbook of Fundamentals* and outlined in Reference Appendices, Joint Appendices JA4.1.2 and JA4.6. The construction assembly in Table 4.6.1 in JA4.6 assumes an exterior air film of R-0.17, a 3/8-inch layer of stucco of R-0.08 (SC01), building paper of R-0.06 (BP01), sheathing, or continuous insulation layer, if present, the cavity insulation/framing layer, 1/2-inch gypsum board of R-0.45 (GP01), and an interior air film 0.68. The framing factor is assumed to be 25 percent for 16-inch stud spacing, 22 percent for 24-inch spacing, and 17 percent for advanced wall system (AWS). Actual cavity depth is 3.5 inches for 2x4, 5.5 inches for 2x6.

Table 3-15: Assembly Components for AWS in Figure 4-46

Layer	Assembly Type: Wall 2x6 @ 24-inches oc AWS Framing Material: Wood Assembly Components	R-Value Cavity (R _c)	R-Value Frame (R _f)	R-Value Header (R _h)
0	Frame Factor	78%	17%	5%
1	Outside Air Film	0.17	0.17	0.17
2	Building Paper	0.06	0.06	0.06
3	3/8-Inch Single Coat Stucco	0.08	0.08	0.08
4	R4 Continuous Insulation (1" EPS)	4	4	4
5	7/16-Inch Continuous Oriented Strand Board Sheathing (OSB)	0.44	0.44	0.44
6	R-20 Fiberglass Batts	20.0	--	--
7	Header Assembly – 2x Wood			1.485
8	Header Assembly – 2.5 Inches of R4 Foam			10
9	Header Assembly – 2x Wood			1.485
10	2x6 Framing @ R-0.99/Inch	--	5.445	--
11	½-Inch gypsum board	0.45	0.45	0.45
12	Inside Air Film	0.68	0.68	0.68
	Subtotal R-Values	25.88	11.325	18.85
	U-Factors (Frame % x 1/R)	0.0301	0.0150	0.0027
	Assembly U-Factor $(\frac{U_{Cavity} + U_{Frame} + U_{Header}}{3})$	Assembly U-Factor	0.048	0.048

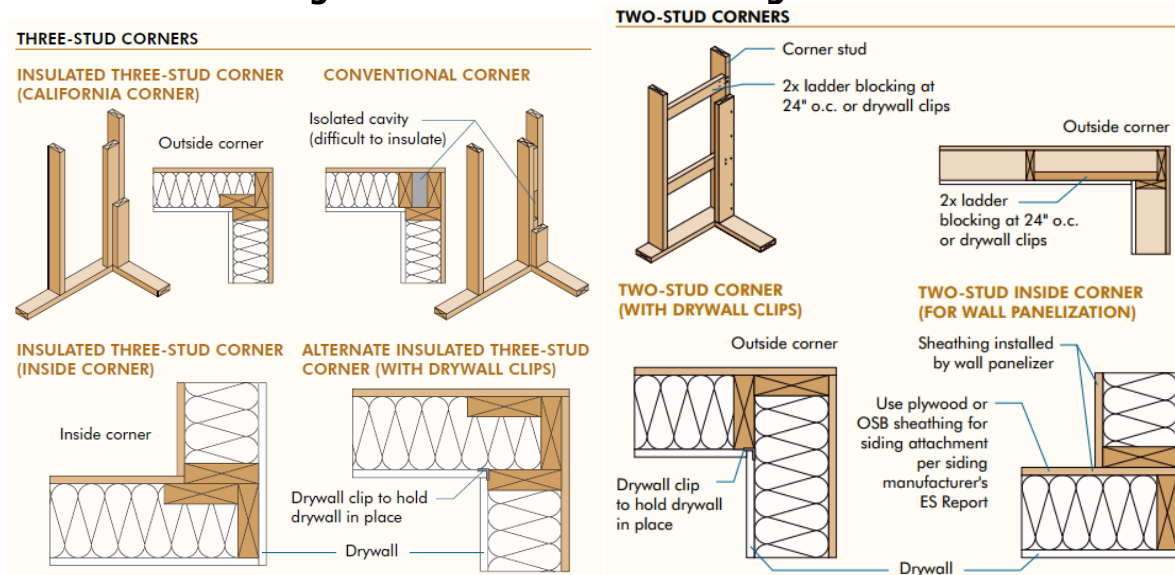
Source: California Energy commission

Note for Building Inspectors: While AWS represents a range of practices, it must be adequately inspected to ensure framing contractors have adhered to all best practice construction techniques throughout the exterior envelope.

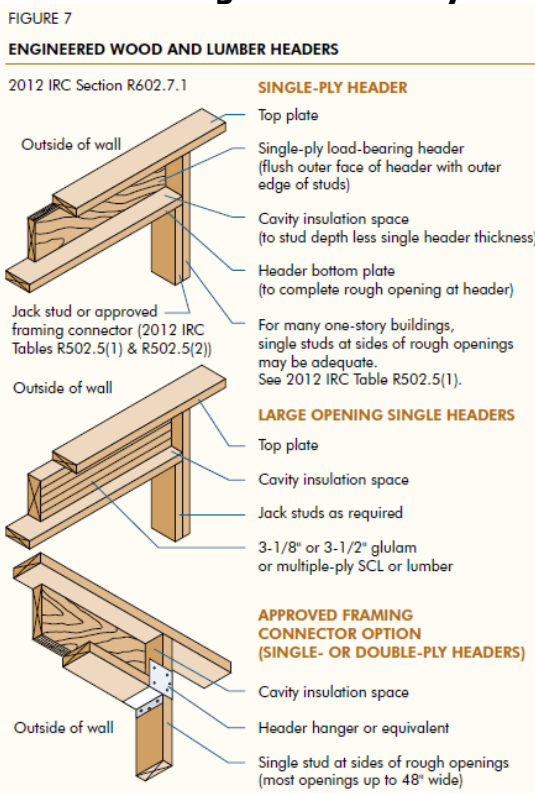
Examples of construction practices for AWS that can be used as a general guide for building inspectors:

1. Use a minimum 2x6 at 24-inches on-center wall framing.
2. Use precise engineering of headers on load-bearing walls.
3. Install 2x4, 2x6, or I-joist headers on exterior non-load-bearing walls.

4. Eliminate cripple studs at window and door openings less than 4 feet wide.
5. Align window/door openings with standard stud spacing.
6. The king stud, on at least one side of the window/door opening, must take the place of an on-layout AWS stud.
7. Use an insulated corner, either a two-stud corner or a California (three-stud) corners, as in the examples provided in Figure 3-47.
8. Nailing for interior gypsum board can be accomplished with drywall clips, 1x nailer strip, recycled plastic nailing strip. Drywall clips reduce the potential for drywall cracking.
9. Use ladder block where interior partitions intersect exterior walls, instead of three-stud channels.
10. Eliminate unnecessary double-floor joists underneath nonbearing walls.
11. Use metal let-in T-bracing or other methods on nonshear walls to allow full insulation.
12. Include detailed framing plans and elevations on the construction permit plan set.
13. Optimize house design for efficient material use (for example, reducing header spans, designing exterior surfaces in 2-foot modules, designing clear spans to eliminate interior bearing walls).
14. Build with “insulated headers.” An example of a single-ply insulated header is provided in Figure 3-48. See Reference Appendices, Residential Appendix RA3.5 for more information.
15. Use engineered lumber. Examples include “I”-joists, open web floor trusses, 2x raised heel roof trusses, glulam beams, laminated veneer lumber (LVL), laminated strand lumber (LSL), parallel strand lumber (PSL), oriented strand board (OSB).
16. Eliminate trimmers at window and door opening headers less than 4 feet wide, only when rated hangers are used and noted on the plans.
17. Use 2x4 or 2x3 interior nonload-bearing walls.
18. Integrate framing design with HVAC system.
19. Use “inset” shear wall panels.

Figure 3-47: Advanced Framing Corners

Source: APA Advanced Framing Guide

Figure 3-48: Headers Designs with Cavity Insulation Space

Source: APA Advanced Framing Guide

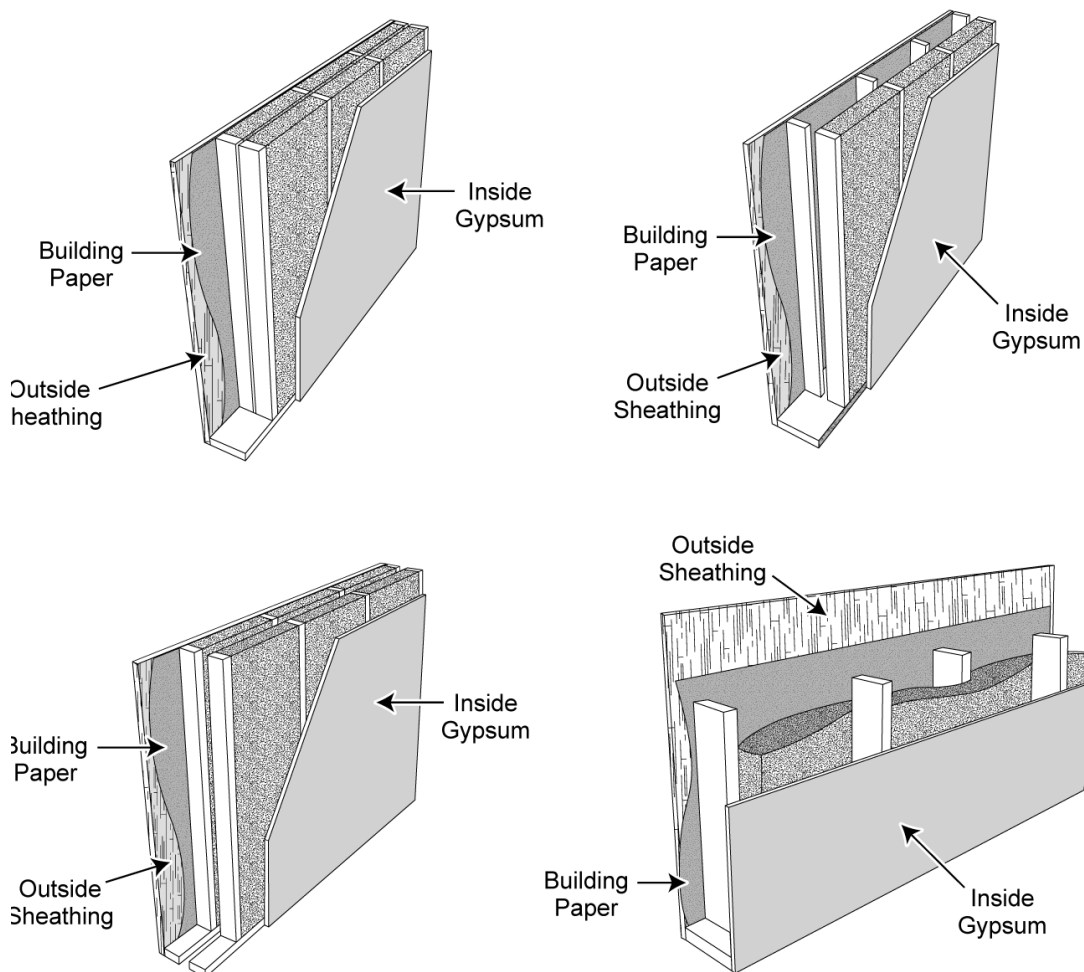
- Double and Staggered Wall Assemblies.** Double-wall and staggered-wall systems were developed to better accommodate electrical and plumbing systems, allow higher levels of insulation, and provide greater sound reduction. The advantages of these types of wall systems are the following:

1. Smaller dimensional lumber can be used.
2. It is easier to install insulation properly.
3. It eliminates thermal bridging through the framing.
4. It reduces sound transmission through the wall.

With double walls, insulation may be on one side of the wall or on both (higher R-values). It is not uncommon to find double walls with insulation installed within the outside wall cavities, leaving the inside wall sections open for wiring and plumbing (Figure 3-49).

With staggered walls, thermal batt insulation may be installed horizontally or vertically, butting the sides of the insulation until the cavity across the entire wall section is completely filled.

Figure 349 Double Staggered Wall Assemblies



Source: California Statewide CASE Team

3.6.7 Metal Framing

A change from wood framing to metal framing can significantly affect compliance. Metal-framed assemblies are often chosen where greater structural integrity is necessary or in climate conditions where greater durability is necessary to protect from the effects of excessive moisture exposure. Metal-framed wall construction generally requires a continuous layer of rigid insulation to meet the mandatory minimum wall insulation levels and the prescriptive requirements since metal is more conductive than wood. In Reference Appendices, Joint Appendix JA4, Table 4.2.4 and Table 4.2.5 have U-factors for metal-framed ceiling/roof constructions. Table 4.3.4 has U-factors for metal-framed walls. Table 4.4.4 and Table 4.4.5 have U-factors for metal-framed floors.

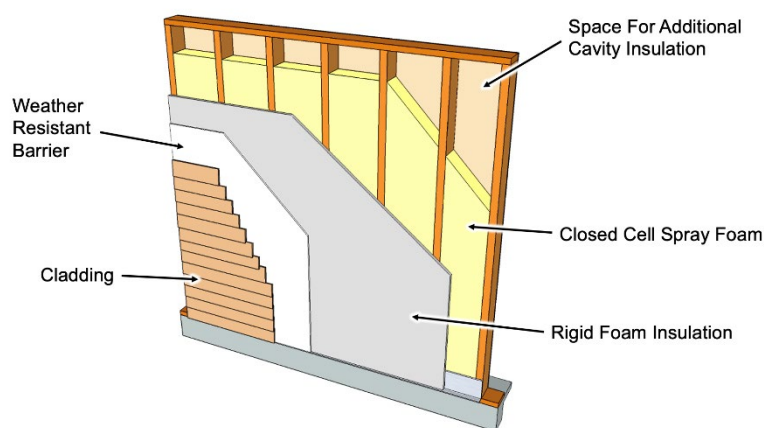
To comply prescriptively, a non-wood-framed assembly, such as a metal-framed assembly, must have an assembly U-factor that is equal to or less than the U-factor of the wood-framed assembly for that climate zone.

3.6.8 Structural Foam Wall Systems

The high performance structural foam wall assembly is an advanced assembly system that consists of closed cell spray foam (ccSPF) placed in the cavity bonded to wood framing and continuous rigid board insulation on the exterior of the frame. The bond that occurs between the ccSPF, the framing, and the continuous rigid insulation can provide code-compliant wind and seismic structural load resistance without the use of OSB sheathing (Figure 3-50).

A builder can configure the thicknesses of the cavity ccSPF, rigid insulation, and alternative cavity insulation to attain U-factors of 0.050 or better in 2x4 at 24-inches on center assembly. The structural foam wall assembly can be combined with advanced framing or OVE techniques to increase energy and resource efficiency while reducing material and labor costs.

Figure 3-50: Example Structural Foam Wall System



Source: California Energy Commission

Note for Contractors/Installers: Structural foam wall systems use ccSPF to insulate, air seal, and structurally bond exterior foam sheathing with wall framing to allow builders to construct 2x4 at 24-inches on center, while improving structural and thermal performance.

3.6.9 RESERVED

Raised Floor Insulation Requirements

Buildings that have crawl space foundations must meet mandatory requirements for insulation of a raised floor separating the unconditioned crawl space from conditioned space above (§150.0[d]). There also are prescriptive requirements for insulating raised floors in §150.1(c)1C.

An alternative to underfloor insulation is insulating the stem wall of the foundation crawl space. Insulating the crawl space foundation can improve the thermal efficiency of the floor system by:

1. Reducing heat transfer into the unconditioned crawl space.
2. Reducing moisture buildup in the crawl space.
3. Minimizing insulation exposure to adverse weather prior to enclosing the building shell.

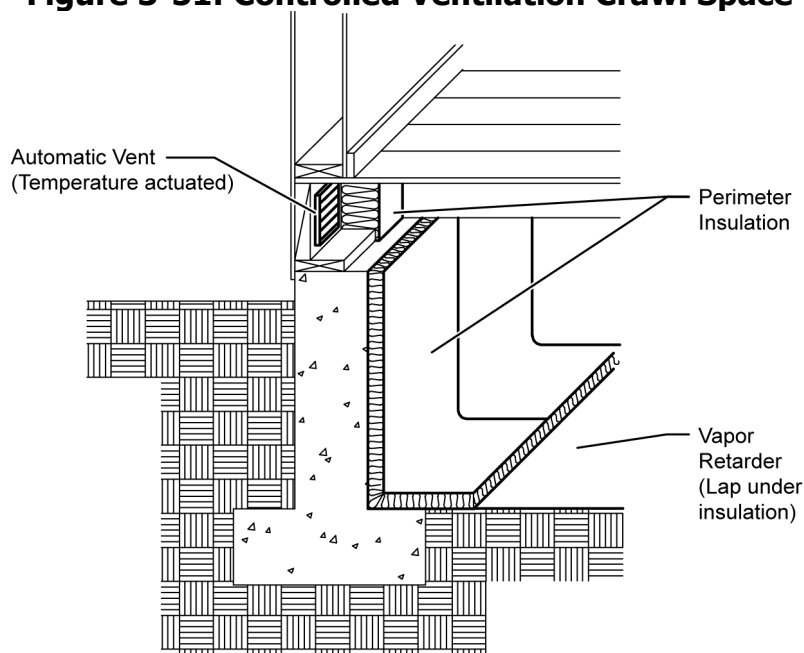
Eligibility Criteria. The following eligibility criteria in Reference Appendices, Residential Appendix RA4.5.1 are required to be met to use the CVC energy compliance credit:

1. **Ventilation:** All crawl space vents must have automatic vent dampers. Automatic vent dampers must be shown on the building plans and installed. Dampers shall be temperature actuated to be fully closed at about 40°F and fully open at about 70°F. Cross-ventilation consisting of the required vent area shall be distributed between opposing foundation walls.
2. **Insulation:** The R-value of insulation placed on the foundation stem wall shall be equal to or greater than the wall insulation above the raised floor. Stem wall insulation shall run vertically along the stem wall and horizontally across the crawl space floor for a distance of 2 feet (24 inches).
3. **Direct Earth Contact:** Foam plastic insulation used for crawl space insulation having direct earth contact shall be a closed-cell, water-resistant material and meet the slab edge insulation requirements for water absorption and water vapor transmission rate specified in the mandatory requirements (§110.8[g]1).
4. **Vapor Retarder:** A Class I or Class II vapor retarder rated as 1.0 perm or less must be placed over the earthen floor of the crawl space to reduce moisture entry and protect insulation from condensation in accordance with Reference Appendices, Residential Appendix RA4.5.1. This requires essentially a polyethylene-type ground cover having a minimum 6 mil thickness (0.006

inch) or approved equal. The vapor retarder must be overlapped a minimum of 6 inches at joints and shall extend over the top of footings and piers. All overlapping of joints shall be sealed with tape, caulk, or mastic.

- Penetrations, tears, and holes in the vapor barrier shall be sealed with tape, caulk, or mastic.
- Edges of the vapor retarder shall be turned up a minimum of 4 inches at the stem wall and securely fastened and before insulation is installed.
- In sloping crawl space ground soil areas, the vapor retarder shall be securely held in place using fastening methods such as spiked with 5-inch gutter nails, then have proper sealing of penetration holes.
- The vapor retarder shall be shown on the plans.

Figure 3-51: Controlled Ventilation Crawl Space



Source: California Energy Commission

Site Drainage. Crawl space buildings are susceptible to moisture ponding when good drainage and/or moisture removal designs are not employed. All building designs should ensure that proper site engineering and drainage away from the building is maintained. This includes landscaping techniques that emphasize sound water management strategies.

- **Ground Water and Soils.** Local groundwater tables at maximum winter recharge elevation should be below the lowest excavated elevation of the site foundation. Sites that are well-drained and that do not have surface water problems are generally good candidates for this stem wall insulation strategy. However, allowance for this alternative insulating technique is entirely at the enforcement agency's discretion. The building permit applicant should be prepared to provide

supporting information that site drainage strategies (for example, perimeter drainage techniques) will prevent potential moisture concerns.

3.6.10 HERS-Verified Reduced Building Air Leakage RA3.8

A. An energy credit is allowed for single-family buildings through the performance approach when the rate of envelope air leakage of the building is less than the air leakage rate assumed for the standard design building of 5 ACH50.

Note for HERS Raters: A third-party HERS Rater shall verify the air leakage rate shown on compliance documentation through diagnostic testing of the air leakage of the building.

Figure 3-52: Blower Door Testing



Blower Door Testing. The blower door air leakage testing involves closing all the windows and doors; pressurizing the house with a special fan, usually positioned in a doorway (Figure 3-52); and measuring the leakage rate, measured in cubic feet per minute at a 50 Pa pressure difference (CFM50).

The measurement procedure is described in Reference Appendices, Residential Appendix RA3.8 and was derived from the Residential Energy Services Network's (RESNET) Mortgage Industry National Home Energy Rating Standards, Standard 800, which is based on ASTM E779 air-tightness measurement protocols. This procedure requires the use of software consistent with ASTM E779. This test method is intended to produce a measure of the airtightness of a building envelope for determining the energy credit allowance for reduced building air leakage.

Note for Contractors/Installers: Tips for Implementing the Reduced Building Air Leakage Compliance Credit

1. This procedure shall be used only to verify the building air leakage rate before the building construction permit is finalized when an energy credit for reduced air leakage is being claimed on compliance documentation.
2. The HERS Rater shall measure the building air leakage rate to ensure measured air leakage is less than or equal to the building air leakage rate stated on the certificate of compliance and all other required compliance documentation. HERS-verified building air leakage shall be documented on compliance forms.
3. This is a whole-building credit; therefore, no credit is allowed for the installation of envelope requirements that may help reduce the air leakage rate of the building, such as for an exterior air retarding wrap or for an air barrier material or assembly meeting the requirements described in Section 3.5.8 under Quality Insulation Installation (QII).

3.7 Alternative Construction Assemblies

3.7.1 Log Homes

Log walls are typically made from trees that have been cut into logs that have not been milled into conventional lumber. Logs used for walls, roofs, and floor systems may be milled or laminated by the manufacturer or supplier to meet specific dimensions and fitting and finishing conditions.

Log homes are an alternative construction type used in some parts of California. Log home companies promote the aesthetic qualities of solid wood construction and can package the logs and deliver them directly to a building site. Some companies provide log wall, roof, and floor systems with special insulating channels or other techniques to minimize the effect of air infiltration between log members and to increase the thermal benefit of the logs.

Log walls do not have framing members like conventional wood stud walls. Section 150.0(c)3 says that opaque nonframed assemblies need to have an overall maximum U-factor of 0.102, which is equivalent to a 2x4 R-13 wood-framed assembly. Per Reference Appendices, Joint Appendix JA4 Table 4.3.11, any log wall 8 inches or more in diameter would meet this requirement, but less than 8 inches would not.

In prescriptive compliance, log walls must meet the same thermal requirements as other construction types. The prescriptive requirements for mass walls are less stringent than the criteria for wood-framed walls. Reduced insulation is allowed because the effects of the thermal mass (interior and exterior) can compensate for less insulation. Footnotes 5 and 6

to Table 150.1-A define the prescriptive mass wall as having heat capacity (HC) 7.0 Btu/°F-ft² or more, depending on whether the insulation is interior or exterior.

For performance compliance, consult the compliance software vendor's documentation for any unique modeling requirements for mass walls using values from the Reference Appendices, Joint Appendix.

The thermal performance of log walls is shown in JA4 Table 4.3.11. The U-factor ranges from 0.132 for a 6-inch wall to 0.053 for a 16-inch wall. The U-factor of an 8-inch wall is 0.102, which complies with the mandatory U-factor requirements. U-factors for other log wall constructions (not shown in JA4) would have to be approved by the Energy Commission through the exceptional methods process.

Log walls have a heat capacity that exceeds conventional construction, as seen in JA4 Table 4.3.11 (Thermal Properties of Log Home Walls) (Table 3-16). The thermal mass effects of log home construction can be accounted for within the performance approach.

Table 3-16: Thermal Properties of Log Home Walls (JA4 Table 4.3.11)

Left blank	Left blank	U-Factor	Heat Capacity (HC)
Log Diameter	A	A	A
6"	1	0.132	5.19
8"	2	0.102	6.92
10"	3	0.083	8.65
12"	4	0.070	10.37
14"	5	0.060	12.10
16"	6	0.053	13.83

Source: California Energy Commission

Air Infiltration. Air infiltration between log walls can be considerably different among manufacturers depending upon the construction technique used. For compliance, infiltration is always assumed to be equivalent to a wood-frame building. The builder should consider using a blower door test to find and seal leaks through the exterior walls.

3.7.2 Straw Bale

Straw bale construction is a building method that uses bales of straw (commonly wheat, rice, rye, and oat straw) as structural and insulating elements of the building. Straw bale construction is regulated within the California Building Code (CBC), and specific guidelines are established for moisture content, bale density, seismic bracing, weather protection, and other structural requirements.

The Energy Code has determined specific thermal properties for straw bale walls and thermal mass benefits associated with this type of construction. The performance compliance approach can be used to model the heat capacity characteristics of straw bales.

Straw bales that are 22 inches by 16 inches are assumed to have a thermal resistance of R-30, when stacked so the walls are either 22 inches wide or 16 inches wide. The minimum density of load bearing walls is 7.0 lb/ft³, and this value or the actual density may be used for modeling straw bale walls in the performance approach. Specific heat is set to 0.32 Btu/lb-°F. Volumetric heat capacity (used in some computer programs) is calculated as density times specific heat. At a density of 7 lb/ft³, for example, the volumetric heat capacity of the straw bale is 2.24, and 6.34 Btu/ft³-°F for the entire wall assembly. See Reference Appendices, Joint Appendix JA4 Table 4.3.12

The minimum dimension of the straw bales when placed in the walls must be 22 inches by 16 inches, and there are no restrictions on how the bales are stacked. Due to the higher resistance to heat flow across the grain of the straw, a bale laid on edge with a nominal 16-inch horizontal thickness has the same R-Value (R-30) as a bale laid flat.

The nature of straw bale construction provides an effective air barrier. For compliance, infiltration is assumed to be equivalent to framed walls.

3.7.3 Structural Insulated Panels (SIPs)

A. Structural insulated panels (SIPs) are a nonframed advanced construction system that consists of rigid foam insulation sandwiched between two sheets of board. The board can be sheet metal, plywood, cement, or oriented strand board (OSB), and the foam can be expanded polystyrene foam (EPS), extruded polystyrene foam (XPS) or polyurethane (PUR), or polyisocyanurate (ISO) foam. SIPs combine several components of conventional building, such as studs and joists, insulation, vapor barrier, and air barrier. They can be used for many different applications, such as exterior walls, roofs, floors, and foundation systems. Little or no structural framing penetrates the insulation layer. Panels are typically manufactured at a factory and shipped to the job site in assemblies that can be as large as 8 feet by 24 feet.

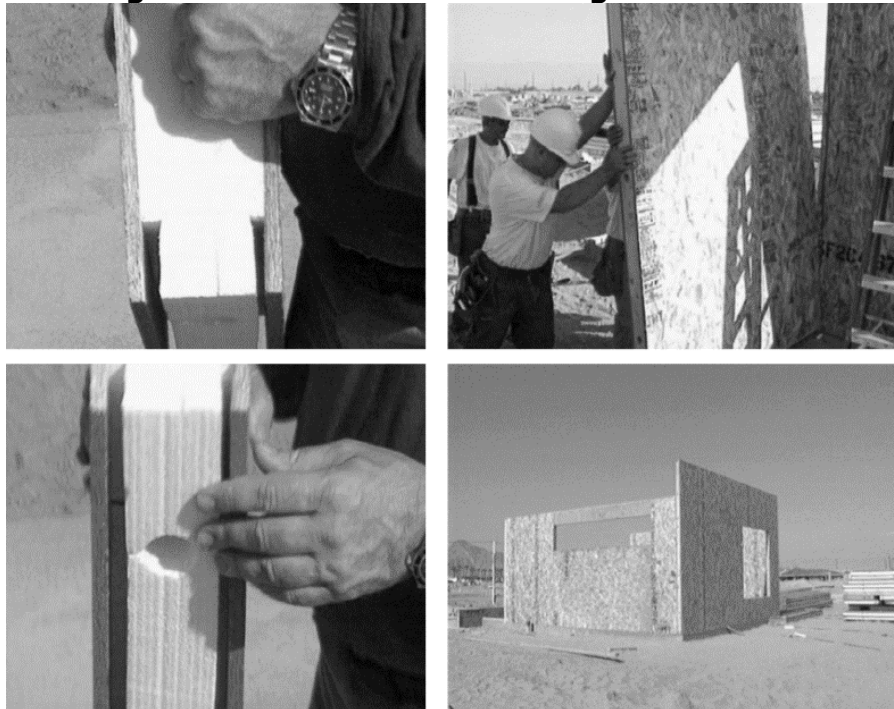
Note for Architects/Designers: SIPs U-Factors for Compliance

In the field, the SIPs panels are joined in one of three ways, as shown in Figure 3-53:

1. Single or double 2x splines
2. I-joists
3. With OSB splines.

The choice of these options affects thermal performance and structural capacity. The 2x and I-joist spline types fit in a recess of the foam core, between the two layers of plywood or OSB. Reference Appendices, Joint Appendix JA4 Table 4.2.3 contains U-factors for roof/ceiling assemblies, JA4 Table 4.3.2 has U-factors for SIPS wall assemblies, and JA4 Table 4.4.3 has U-factors for SIPS floor constructions. U-factors used for compliance must be taken from these tables or by using Commission-approved performance compliance software.

Figure 3-53: Methods of Joining SIPS Panels



Source: California Energy Commission

3.7.4 Insulating Concrete Forms (ICF)

A. Insulating concrete forms (ICFs) are a system of formwork for concrete that stays in place as permanent building insulation and can be used for cast-in-place reinforced above- and below-grade concrete walls, floors, and roofs. They are interlocking modular units that can be dry-stacked (without mortar) and filled with concrete as a single concrete masonry unit (CMU). ICFs lock together externally and have internal metal or plastic ties to hold the outer layer(s) of insulation to create a concrete form and are manufactured from several materials, including expanded and extruded polystyrene foam, polyurethane foam, cement-bonded wood fiber, and cement-bonded polystyrene beads.

Three factors contribute to the energy efficiency of buildings using an ICF wall:

1. Continuous rigid insulation on both sides of a high-mass core
2. Elimination of thermal bridging from wood framing components
3. A high degree of airtightness inherent to this method of construction.

Climate zones with large daily temperature fluctuations have the greatest potential to benefit from the time lag and temperature dampening effects of these high-mass envelope systems. However, this combination of mass and insulation is beneficial in almost all climates, with the possible exception of mild coastal climate zones.

There are three basic types of ICFs:

1. Flat wall - A flat wall ICF results in a wall with a consistent and continuous thickness of concrete.
2. Waffle-grid - A waffle-grid ICF creates a concrete waffle pattern, an uninterrupted grid, with some concrete sections thicker than others.
3. Screen-grid - A screen-grid ICF consists of a discrete post-and-beam structure with the concrete completely encapsulated by the foam insulation, except at the intersection of posts and beams.

The insulating panels for all three ICF types are most commonly made from expanded polystyrene (EPS) and extruded polystyrene (XPS) rigid insulation boards. Insulating panels also are made from polyurethane (PUR), composites of cement and EPS, and composites of cement and shredded wood fiber, although these tend to be proprietary materials developed by the ICF manufacturer.

Plastic or metal cross-ties, consisting of two flanges and a web, separate the insulating panels and provide structural integrity during the pouring of concrete, resulting in uniform wall thickness. A variety of wall thicknesses can be obtained by changing the length of the web. The area of attachment of the cross-ties to the insulating form provides a secure connection surface located at standard spacing for mechanical attachment of finished materials to the interior and exterior of the wall. ICFs can be used to construct load-bearing and nonload-bearing walls and above- and below-grade walls and can be designed to structurally perform in any seismic zone.

The ICF system is modular and stackable with interlocking edges. The materials can be delivered as preassembled blocks or as planks that require the flanges and web to be assembled during construction. The forms vary in height from 12-inches – 24-inches and are either 4-feet or 8-feet long. Vertical panels come in similar modules but are stacked vertically. ICF panels are typically available with core thickness ranging from 4-inches to 12-inches.

- The thermal aspects of ICFs are represented in Reference Appendices, Joint Appendix JA4 Table 4.3.13.