Report

An Analysis of Metal Roofing Compliance Options for California's Title 24 2005 Energy Standard

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Prepared for:

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Executive Summary

This report addresses the new requirements related to roofs in the 2005 Building Energy Efficiency Standards and their impact on *metal roofs* in particular, with special focus on office buildings and warehouses as examples.

Prescriptive Roof Requirements

In order to comply using the prescriptive path, the 2005 Building Energy Efficiency Standards require that a certified cool roof (reflectance greater than or equal to 0.70 and emissivity no less than 0.75) is installed in all low-rise, low slope non-residential buildings. This cool roof requirement, as well as the roof insulation requirement, do not apply if the space is not heated or cooled.

In addition to the cool roof requirements, the prescriptive method requires roof insulation. The maximum U-factor is 0.051 for most of California, except for the southern coastal areas where the limit is 0.076. A significant change for the 2005 standard is that U-factors used for compliance must be taken from one of a number of tables included in an appendix to the standard. For roofs with metal framing, it will no longer be deemed to comply with the prescriptive insulation requirement if R-19 insulation is installed. The table for metal building roofs (included in Appendix C to this report) shows that some form of continuous insulation would be required to achieve a U-factor of 0.051.

Analysis was done for three roof surface types: unpainted, white-painted, and dark-painted metal roof. The assumed reflectance/emissivity for these surfaces are 0.68/0.10, 0.65/0.80, and 0.25/0.80 respectively. None of these roof surfaces meets the prescriptive cool roof requirement. The white metal roof is close, but its reflectivity is 0.65. Therefore, either the envelope tradeoff compliance method or the whole building performance compliance method must be used.

Envelope Tradeoff Method Analysis

Analysis using the envelope tradeoff method for the office and warehouse examples in climate zones 2 and 13 show that if compliance is achieved through additional roof insulation only, then the required U-factors are:

- Unpainted metal roof: 0.036 to 0.039
- White painted metal roof: 0.048
- Dark painted metal roof: 0.033 to 0.36

The analysis also shows that compliance is possible using improved glazing performance in the office building example (assuming that the roof meets the prescriptive U-factor requirement of 0.051). For the warehouse example, improved glazing is enough only in the case of the white painted roof surface. Because of the small window area, additional roof insulation is also required in addition to high performance windows with the unpainted and dark-painted metal roofs.

The third envelope tradeoff option covered by this analysis is overhangs to shade the windows. These results are similar to the improved window performance results. For the office example is it possible to comply using overhangs (again assuming that the roof meets the prescriptive 0.051 U-factor requirement). For the warehouse, overhangs can achieve compliance with a white painted roof surface, but are not enough with the other two roof surfaces.

Envelope Tradeoff Spreadsheet

A spreadsheet was developed that implements the tradeoff equations, and it can be used to investigate other combinations of measures for compliance.

Whole Building Method Analysis

The whole building simulation compliance method was also used to evaluate metal roof compliance options. The findings of this analysis are that the whole building method ends up being more stringent that the envelope tradeoff method if only roof insulation is changed to achieve compliance. The reason for the difference is that the whole building comparison is based on time dependant valuation of energy in the 2005 standards. Therefore, measures that reduce peak energy consumption have a larger impact, and there is a bigger penalty for not complying with the prescriptive cool roof requirement.

The whole building approach analysis also shows that window overhangs get more credit than under the envelope approach. In addition, reduced lighting power and improved cooling efficiency can be used to show compliance.

Introduction

This report was prepared as a result of work sponsored by the Cool Metal Roofing Coalition. It describes the impact of the nonresidential requirements of the California 2005 Building Energy Efficiency Standards (2005 Standards) on buildings with metal roofs. The report describes the compliance options and the envelope requirements for a metal roof building.

This report covers two example buildings:

- Single-story Office/Retail building measuring 15,000 square feet (100' × 150' × 16'). The entire building is heated and air-conditioned. Lightweight metal-framed wall construction was assumed for wall construction.[1]
- Manufacturing/warehouse facility measuring 50,000 square feet (200' × 250' × 30'). It contains a 3,000 sq.ft. office, with the remaining area devoted to manufacturing processes and the warehouse. Only the office will be heated and air-conditioned. Normal weight hollow CMU blocks were assumed for wall construction.

The first task identifies envelope requirements in the code that impact the above building type.

For each of the two buildings, the report also describes envelope trade-offs required to achieve compliance for three different types of metal roof[2]:

A. Unpainted metal roof with aluminum-zinc alloy finish (Galvalume® or Zincalume®) (Reflectivity = 0.68, Emissivity = 0.10)

B. A white painted metal roof (such as a fluoropolymer coating produced with minimum 70% Kynar® or Hylar® type resin) (Reflectivity = 0.65, Emissivity = 0.80)

C. A dark painted metal roof (such as a fluoropolymer coating produced with minimum 70% Kynar® or Hylar® type resin) (Reflectivity = 0.25, Emissivity = 0.80)

The Standards offer three approaches to compliance:

A. The prescriptive path[3], which requires certified cool roofs. The prescriptive path has other requirements applicable to the building types described above. These have been described in the following chapter. As noted below, the cool roof and roof insulation requirements do not apply to spaces that do not have any heating or cooling.

B. The envelope trade-off method[4] allows for certain trade-offs within the envelope parameters to meet specified heat gain and heat loss factors for compliance. The trade-off method includes building parameters such as insulation of roof and walls, glazing and framing type for fenestration, exterior shades etc. While the heat loss factor depends only on thermal transmittance (U-factor) of the various envelope surfaces, the heat gain factor is also affected by the reflectance and the emissivity of the roof, and orientation and solar heat gain coefficient (SHGC) for fenestration products.

C. The whole building method[5] involves energy simulations to compare the performance of the proposed design to a code-complying baseline design. This method allows trade-offs between performance of different building systems, including envelope,

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[1] See Table IV.11, Appendix C.

[2] These three roof types are from the specifications outlined in the RFP.

[3] Sections 142, 143 (a), 144 through 148. 2005 Building Energy Efficiency Standard.

[4] Section 143 (b). 2005 Building Energy Efficiency Standard.

[5] 2005 Building Energy Efficiency Standard, Non-residential Alternate Calculation Manual

HVAC, lighting, and water-heating. The comparison is based on time-dependent valuation of energy.[6] The hourly electricity and gas simulation results are multiplied by factors that vary by time of day and by season. Therefore, energy consumed during peak periods (as defined by the CEC) counts more than off peak energy. The end result is similar to a comparison of utility costs using time-of-use rates.

[6] Section 102, Section 140 (a),and Section 141. 2005 Building Energy Efficiency Standards

Task 1: Relevant Title-24 2005 Envelope Requirements

Prescriptive Requirements for Roofs

The envelope requirements apply only to spaces that are heated or cooled. Therefore, the roof requirements do not apply to the warehouse portion of the example building if it has no heating or cooling. A space is considered conditioned if it has a system with heating capacity of more than 10 Btu/hr-ft^2 or cooling capacity of more than 5 Btu/hr-ft^2. If only a small portion of a large space is conditioned, then it's possible that the overall heating and cooling capacity falls below these limits, and in that case the envelope requirements do not apply.

There is also an exemption from the standard for spaces that are maintained for process purposes below 55F (such as refrigeration) or above 90F (such as for drying). And spaces with systems that are designed and controlled so that they do not heat the space above 55F or cool the space below 90F are also exempt from the envelope requirements.

The office portion of the warehouse building example would have to be insulated and meet the cool-roof requirements in order to comply using the prescriptive path because it has heating and air-conditioning. However, the skylight requirements, as well as all the lighting requirements, apply to both conditioned and unconditioned spaces.

Cool Roof Surface[7]

The prescriptive requirements of the 2005 Building Energy Efficiency Standards require a cool roof in nonresidential low-slope roof applications. In order to qualify as a cool roof, the roof product must be labeled and meet one of the two following criteria:

A. Have an initial thermal emittance greater than or equal to 0.75, and a minimum initial solar reflectance of 0.70 or greater, when tested in accordance with CRRC-1, or

B. If the roofing product has a minimum initial thermal emittance ($\varepsilon_{initial}$) less than 0.75 when tested in accordance with CRRC-1 (as would be the case with uncoated metal roofs), it can comply with the prescriptive requirements if it has a minimum initial solar reflectance of 0.70 + 0.34 * (0.75 - $\varepsilon_{initial}$) when tested in accordance with CRRC-1. For example, if the emissivity is 0.10 (such as an unpainted metal roof), then it would need a reflectance of at least 0.92 to use the prescriptive compliance path. This equation takes into account both the emittance and reflectance of the surface, so that the overall roof performance is equivalent to that of a cool roof that meets the prescriptive reflectance and emittance criteria specified above. Thus, it requires that the reflectance be higher than 0.70, to compensate for the degradation in thermal performance of the roof due to an emittance lower than 0.75, to still qualify as a cool roof.

Apart from the reflectance and emissivity requirements specified above, liquid applied roof coatings also have to adhere to special application procedures and durability requirements in order to comply.[8]

If the roof does not meet these cool roof criteria, then the envelope trade-off method[9] is an option for compliance. If the roof product is not labeled, the trade-off equation assumes a reflectance of

[7] Section 143 (a) (1) and Section 118 (i). 2005 Building Energy Efficiency Standards.

[8] Table 118-C, 2005 Building Energy Efficiency Standards

[9] See footnote 4.

0.10, irrespective of color or texture of the roof.[10] Therefore, to receive “partial credit” for a roof with reflectance less than 0.70 but greater than 0.10, the product must be tested and labeled.

Roof Insulation[11]

There are two options for the prescriptive roof insulation requirements. The roof construction must either include insulation meeting a specific R-value requirement, or the roof construction must meet a maximum overall thermal conductance (U-factor). The R-value requirement is R-19 for climate zones 1 through 5 and 10 through 16.[12] See Appendix A for a map of California climate zones. The requirement is R-11 for climate zones 6 through 9, which correspond to the southern coastal regions[13]. The corresponding U-factor requirement is 0.051 and 0.076 respectively. To determine the U-factor of a construction, a designer must refer to an appendix to the standard[14] that lists a range of construction types and pre-calculated U-factors.

The 2005 standard states that if a roof has metal framing members or a metal deck, then simply installing insulation meeting the prescriptive R-value between framing members or draped over purlins is not sufficient. In these cases, a continuous layer of rigid insulation is required. This continuous insulation must have a minimum R-value equal to or greater than prescriptive requirement and may be installed either above the roof deck or between the roof deck and the structural members supporting the roof deck. Alternately, a continuous layer of rigid insulation with a minimum R-value of R-10 must be installed either above the roof deck or between the roof deck and the structural members supporting the roof deck; *and* insulation with a minimum R-value equal to the prescriptive value (either R-11 or R-19 depending on climate zone) must be installed between the structural members or draped over the purlins. [15]

For typical metal building construction, this prescriptive roof insulation requirement is challenging to meet. The standard metal building roof insulation method, with R-19 insulation draped over the purlins and compressed under a screw-down roof, provides a U-factor of only 0.098 according to Table IV.7 (Appendix C). Besides the options described in the previous paragraph, there are a number of options in Table IV.7 that will meet the U-factor requirement of 0.051 (or 0.076 for the southern coastal regions). One option to achieve 0.051 is with R-19 batt insulation draped over the purlins and 1 inch rigid foam thermal blocks between the purlins and the metal roof in addition to a layer of R-11 batt insulation above the R-19 and between the purlins. Note that these constructions also require a cool roof to comply.

If the cool roof and prescriptive insulation requirements cannot be met, then the envelope trade-off method and the whole building performance method are alternatives.

Skylights[16]

The 2005 Building Energy Efficiency Standards require that low-rise conditioned or unconditioned enclosed spaces that meet *all* the following requirements must have at least one half of the floor area in the daylit area under skylights.

A. Have a floor area greater than 25,000 ft^2 directly under a roof

B. Ceiling heights greater than 15 ft

C. A lighting power density for general lighting equal to or greater than 0.5 W/ft^2

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[10] Section 143 (b), 2. 2005 Building Energy Efficiency Standards

[11] Section 143 (a) (1). 2005 Building Energy Efficiency Standards

[12] Section 143, Table 143-A. 2005 Building Energy Efficiency Standards

[13] See footnote 12.

[14] Table IV.5 and Table IV.7.ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C

[15] Section 143 (a) 1 C ii. 2005 Building Energy Efficiency Standards

[16] Section 143 (c). 2005 Building Energy Efficiency Standards

If the building meets all of those three criteria, then the minimum skylight area varies between 3.0% and 3.6% of the roof area [17] and is determined by the following factors:

A. Lighting power density

B. Light transmittance of the glazing

C. Thermal transmittance of the glazing

D. Skylight design factors such as height, shape, size and color of the skylight well.

In addition, the maximum skylight area under the prescriptive compliance method cannot exceed five percent of the gross exterior roof area for conditioned spaces, with the exception of atrium spaces with ceiling heights greater than 55 ft. The maximum skylight area for such spaces is limited to 10% of the total roof area.

A daylight control system for electric lighting is also mandated for the daylit area in order to take credit for daylit area.

The above skylight criteria do not apply to buildings in Climate zones 1 (north coast) or 16 (mountains), or to auditoriums, movie theaters, museums, and refrigerated warehouses.

[17] Section 143 (b), 1. Table 143-F. 2005 Building Energy Efficiency Standards

Task 2: Envelope Trade–off Method[18] Evaluation

Low-slope nonresidential roofs that do not meet the cool roof criteria cannot use the prescriptive compliance method, and the envelope trade-off method is the simplest alternative. The trade-off results presented below show how improvements to roof insulation, window glazing and exterior shades can be used to allow the three different metal roof types to comply. These design improvements are chosen as typical options. It may also be possible to comply using other improvements such as additional wall insulation, or combinations of several measures. AEC has developed an Excel spreadsheet for CMRC that allows other combinations to be explored.

Table 1 lists the baseline assumptions made for the envelope surfaces for the two example building types. These assumptions match the prescriptive requirements for each building envelope component.

Table 1: Envelope assumptions for Title-24 baseline buildings.[19]

	Office	**Warehouse**
Roof U-factor	0.051	0.051
Roof construction	Metal framed rafter roof with R-19 insulation between frame and continuous R-7 rigid foam insulation.[20]	Screw down roof with R-13 batt insulation and continuous R-12 rigid foam insulation.[21]
Wall U-factor	0.217	0.650
Wall construction	2"x4" metal frame, 16" o/c with R-13 batt[22].	8" Solid Grouted, med.wt. CMU[23]
Floor construction	Slab-on-grade	Slab-on-grade
Window U-factor	0.47	0.47
Window-wall ratio	25%	5%
Window SHGC	0.47 north 0.36 non-north	0.61 north 0.47 non-north
Window construction	Dual-pane, thermally broken frame, clear glass with low-e coating (different coatings for different SHGC values)	Dual-pane, thermally broken frame, clear glass on north Dual-pane, thermally broken frame, clear glass with low-e coating on non-north

Table 2 shows the roof U-factor that is necessary to trade off for the roof surface not meeting the prescriptive cool roof requirement. The required U-factor was determined using the envelope tradeoff equations and changing only the roof U-factor input until compliance was achieved. Table

[18] See footnote 4.

[19] Based on TABLE 143-A PRESCRIPTIVE ENVELOPE CRITERIA FOR NONRESIDENTIAL BUILDINGS (including relocatable classrooms where manufacturer certifies use only in specific climate zone; not including high-rise residential buildings, guest rooms of hotel/motel buildings)

[20] Table IV.7.ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C. Assumed 48" o/c

[21] Table IV.5 .ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C. Assumed 24" o/c

[22] Table IV.11 .ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C.

[23] Table IV.12 .ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C.

3 shows a number of roof constructions that would meet these lower U-factor requirements. Additional roof construction options can be found in Tables IV.7 and IV.5 in Appendix C.

Table 2: Roof U-factor Required for Envelope Tradeoff Using Only Improved Roof Insulation as a Means to Comply (See Table 3 for Example Roof Constructions)

	Title 24 Cool Roof	**Unpainted Metal Roof**	**White Painted Metal Roof**	**Dark Painted Metal Roof**
Warehouse/Manufacturing CZ 2	0.051	0.036	0.048	0.033
Warehouse/Manufacturing CZ 13	0.051	0.039	0.048	0.036
Office CZ 2	0.051	0.038	0.048	0.033
Office CZ 13	0.051	0.039	0.048	0.035

Table 3: Examples of Roof Constructions that Can Provide the U-factors Listed in Table 2

Roof U-factor	**Example Constructions From Table IV.7 and IV.5 (Appendix C)** [24, 25]
0.051	Metal framed rafter roof with R-19 insulation between frame and continuous R-7 rigid foam insulation
0.051	Screw down roof with R-13 batt insulation and continuous R-12 rigid foam insulation.
0.048	Screw down metal roof with R-20 continuous foam board insulation
0.048	Metal framed rafter roof with R-25 batt between framing members + R-6 continuous rigid foam insulation
0.045	Screw down roof with R-19 batt between framing members + R-12 continuous insulation
0.044	Screw down roof with R-13 batt between framing members + R-15 continuous insulation
0.040	R-19 batt between framing members + R-15 continuous insulation
0.039	Metal framed rafter roof with R-30 batt between framing members + R-14 continuous foam board insulation
0.038	Metal framed rafter roof with R-19 batt between framing members + R-14 continuous insulation
0.036	Screw down metal roof without thermal block with R-13 batt between framing members + R-20 continuous insulation
0.035	Metal framed rafter roof with R-25 batt between framing members + R-14 continuous insulation
0.033	Screw down roof without thermal block with R-19 batt between framing members + R-20 continuous insulation
0.033	Metal framed rafter roof with R-30 batt between framing members + R-14 continuous insulation

[24] Please note that these construction assemblies only serve to represent the minimum complying construction. Some of these may not be commonly used. Please refer to Appendix C to find a construction that is more commonly used and still satisfies the minimum compliance requirement.

[25] Cases where continuous insulation is required for compliance, it can be installed either over or under the roof – as long as it is not interrupted by framing members. If this can't be done for "through-fastened panel roofs" then a standing seam metal roof will have to be installed.

Table 4 is similar to Table 2 above except that it shows improvements to glazing Solar Heat Gain Coefficient (SHGC) that will achieve compliance instead of improvements to roof insulation. Only modest improvements are necessary under the white painted metal roof. Under the other roof surfaces, the warehouse example cannot comply using improvements to the glazing alone because there is relatively little window area. Table 5 describes the glass types that will meet these SHGC values.

Table 4: Glazing Solar Heat Gain Coefficient (SHGC) Required for Envelope Tradeoff Compliance, Showing Maximum SHGC on the North/Non-north.
(In Some Cases Additional Roof Insulation Beyond the Prescriptive 0.051 U-factor is Required)

	Title 24 Cool Roof	**Unpainted Metal Roof**	**White Painted Metal Roof**	**Dark Painted Metal Roof**
Warehouse/Manufacturing CZ 2	0.61/0.47	0.24/0.24 (+ roof 0.044)	0.61/0.36	0.24/0.24 (+ roof 0.40)
Warehouse/Manufacturing CZ 13	0.61/0.47	0.24/0.24 (+ roof 0.044)	0.61/0.36	0.24/0.24 (+ roof 0.40)
Office CZ 2	0.47/0.36	0.47/0.24	0.47/0.33	0.23/0.23
Office CZ 13	0.47/0.36	0.47/0.24	0.47/0.33	0.24/0.24

Table 5: Glazing Types that meet SHGC Values listed in Table 4.

SHGC	**Description**	**Incremental Cost (see Appendix D for more detail)**
0.61	Double pane, clear glass, no coating	--
0.47	Double pane, clear glass, low-e coating	~$3.00 per ft^2
0.36	Double pane, clear glass, low-e coating	~$3.00 per ft^2
0.33	Double pane, clear glass, low-e coating	~$3.00 per ft^2
0.24	Double pane, high performance tinted glass on outer pane (e.g. Evergreen, Azurlite), low-e coating	~$5.00 per ft^2
0.23	Double pane, high performance tinted glass on outer pane (e.g. Evergreen, Azurlite), low-e coating	~$5.00 per ft^2

Table 6 shows how window overhangs can be used for compliance. The table lists the overhang projection factor necessary to make up for the roof not complying with the prescriptive cool roof criteria. The projection factor is defined as the ratio of the overhang depth (horizontal distance from the surface of the window to the outer edge of the overhang) to the overhang height (vertical distance from the bottom of the window to the bottom of the overhang). In a few cases, the warehouse cannot comply using window shading alone, and additional roof insulation is also required.

Table 6: Window Shade Overhang Projection Factor (PF) [26] *Required for Envelope Tradeoff Compliance (In Some Cases Additional Roof Insulation Beyond the Prescriptive 0.051 U-factor is Required)*

	Title 24 Cool Roof	**Unpainted Metal Roof**	**White Painted Metal Roof**	**Dark Painted Metal Roof**
Warehouse/Manufacturing CZ 2	0.0 PF	1.0 PF (+ roof 0.044)*	0.25 PF	1.0 (+ roof 0.40) *
Warehouse/Manufacturing CZ 13	0.0 PF	1.0 PF (+ roof 0.044) *	0.25 PF	1.0 (+ roof 0.40) *
Office CZ 2	0.0 PF	0.5 PF	0.10 PF	0.75 PF
Office CZ 13	0.0 PF	0.5 PF	0.10 PF	0.75 PF

* Installing only exterior shades equal to height of the window (i.e. PF = 1) in the warehouse is still not adequate to comply

An important feature of the building envelope tradeoff method is that it includes an equation that accounts for the impact of roof surfaces with emissivity lower than 0.75. Equation 143-E, in Section 143 (b) of the standards, adjusts the value for initial reflectance that is used in the envelope trade-off equations to account for the relatively poorer performance of a surface that has a lower emittance. It is intended to account for both the emissivity and reflectivity of the roof, even though the emittance is not directly used as a variable in the envelope trade-off equation. If the roofing product has an emittance less than 0.75 the value is calculated by the following equation:

$$\rho_{Ri_{prop}} = -0.448 + 1.121*R + 0.524*E$$

Where

$\rho_{Ri_{prop}}$ = the initial solar reflectance of the proposed design roofing product as used in the envelope tradeoff equation

R = actual initial reflectance of the roofing product

E = emittance of the roofing product

The calculated value of $\rho_{Ri_{prop}}$ from the above equation shall not be larger than R or less than 0.10.

[26] See footnote**Error! Bookmark not defined.**

Task 3 Whole Building Compliance Approach

This section of the report describes whole building compliance options for a metal roof building. The whole building compliance approach applies only to conditioned spaces in a building. The whole building method involves energy simulations to compare the performance of the proposed design to a code-complying baseline design. This method allows more flexibility for achieving compliance by allowing trade-offs between performance of different building systems, including envelope, HVAC, lighting, and water-heating. The whole building method requires that the *aged value of absorptance* for the roof is specified to account for degradation due to dust and UV action over time[27]. A *time dependant value of energy*, which uses an hourly multiplier for source energy, is used for calculating the source energy. This method of energy evaluation shifts the focus from alternatives that primarily impact reduction of total energy consumption (due to heat loss and heat gain) in the envelope trade-off method, to alternatives that have a significant impact on reducing peak energy consumption in a building.

This analysis looks at the single-story office/retail example described earlier. The building covers 15,000 square feet (100’ × 150’ × 16’). Lightweight metal-framed construction was assumed for roof and wall. The warehouse example was not analyzed because as an unconditioned space the whole building method is not applicable.

This analysis covers the same three metal roof types that were evaluated in the building envelope tradeoff method discussed in the previous section.

A. Unpainted metal roof with aluminum-zinc alloy finish (Galvalume® or Zincalume®) (Reflectivity = 0.68, Emissivity = 0.10)

B. A white painted metal roof (such as a fluoropolymer coating produced with minimum 70% Kynar® or Hylar® type resin) (Reflectivity = 0.65, Emissivity = 0.80)

C. A dark painted metal roof (such as a fluoropolymer coating produced with minimum 70% Kynar® or Hylar® type resin) (Reflectivity = 0.25, Emissivity = 0.80)

The analysis results presented below show how improvements to roof insulation, addition of exterior shades, efficient lighting design, and improvements to cooling efficiency can be used to allow these three different metal roof types to comply. These design improvements are chosen as typical options. It may also be possible to comply using other improvements such as additional wall insulation, high performance fenestration, variable speed fan control (in certain cases) or combinations of several measures.

This analysis was performed using VisualDOE 3.1, which is an interface to DOE2.1E. The Title 24 compliance modeling rules were implemented manually because compliance software was not yet available for the 2005 standard. The major difference from the 2001 method is the time dependant valuation of energy. For this analysis, the hourly energy results were taken from the simulation model and the time dependant values were calculated in a spreadsheet. Table 7 lists the baseline simulation model assumptions.

[27] Section 2.3.2.3, Equation N2-2, 2005 Non-Residential ACM Manual

Table 7: Envelope assumptions for Title-24 baseline building[28]

ENVELOPE		*Description/Notes*
Roof/Ceiling U-factor	0.051	R-19 insulation between frame and continuous R-7 rigid insulation[29].
Reflectivity	0.70	
Aged Reflectivity	0.45[30]	2005 Non-Residential ACM requires that aged reflectivity is used.
Emissivity	0.75	
Wall U-factor	0.217	2"x4" metal frame, 16" o/c with R-13 batt[31]
Floor/Soffit		Slab-on-grade
Windows U-factor	0.47	Dual – pane with non-aluminum or thermally broken aluminum frame[32].
Windows Solar Heat Gain Coefficient (North/Non-north), 25% WWR	0.47/0.36	Dual Pane Clear Low-e/ Dual Pane Clear Low-e
SPACE CONDITIONS[33]		
Occupancy Density (s.f./ person)	100	
Plug Load (w/s.f.)	1.34	
Lighting Power Density (w/s.f.)	1.1	Complete building method lighting power allowance for office buildings, Table 146-B of the standard.
Ventilation (cfm/person)	15	
HVAC[34]		
System Type	Packaged VAV	Electric cooling and gas heating
EER	9.5[35]	
Economizer control	Yes	
Fan Efficiency (w/cfm)	1.25	
Fan Position	Draw-through	In-air stream
Fan control	Variable Speed Drive	
Boiler Efficiency	75%	

Table 8 and Table 9 show that the additional roof insulation required in order to comply is greater in the whole building approach than the envelope trade-off method. This is largely due to the time-dependant value of energy used in the whole building compliance approach, where peak loads carry more weight. Therefore, there is a bigger penalty for not meeting the cool roof requirement when using the whole building method.

[28] Based on TABLE 143-A PRESCRIPTIVE ENVELOPE CRITERIA FOR NONRESIDENTIAL BUILDINGS (including relocatable classrooms where manufacturer certifies use only in specific climate zone; not including high-rise residential buildings, guest rooms of hotel/motel buildings)

[29] Table IV.5 .ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C. Assumed 24" o/c

[30] Section 2.3.2.3, Equation N2-2, 2005 Non-Residential ACM Manual

[31] Table IV.11 ACM Appendix IV – U-Factor, C-Factor and Thermal Mass Data. See Appendix C.

[32] Table 13, 2001 ASHRAE Fundamentals Handbook

[33] Table IV2-2. 2005 Non-Residential ACM Manual

[34] 2005 Non-Residential ACM Manual

[35] Table 112. Section 112. 2005 Building Energy Efficiency Standards

Table 8: Roof Insulation Compliance Alternatives for Office Building Example Using Whole Building Trade-off Method (Climate Zone 2) [36]

	Whole Building Compliance Results		Envelope Tradeoff Compliance Results (from previous section of this report)	
	U-Factor	*Description*	*U-Factor*	*Description*
T-24 Baseline	0.051	R-19 metal framed construction + R-7 continuous rigid insulation	0.051	R-19 metal framed construction + R-7 continuous rigid insulation
Unpainted metal roof	0.031	R-38 metal framed construction + R-14 continuous rigid insulation	0.038	R-19 metal framed construction + R-14 continuous rigid insulation
White painted metal roof	0.044	R-19 metal framed construction + R-10 continuous rigid insulation	0.048	R-25 metal framed construction + R-6 continuous rigid insulation
Dark painted metal roof	0.031	R-38 metal framed construction + R-14 continuous rigid insulation	0.033	R-30 metal framed construction + R-14 continuous rigid insulation

Table 9: Roof Insulation Compliance Alternatives for Office Building Example Using Whole Building Trade-off Method (Climate Zone 13)

	Whole Building Compliance Results		Envelope Tradeoff Compliance Results (from previous section of this report)	
	U-Factor	*Description*	*U-Factor*	*Description*
T-24 Baseline	0.051	R-19 metal framed construction + R-7 continuous rigid insulation	0.051	R-19 metal framed construction + R-7 continuous rigid insulation
Unpainted metal roof	0.033	R-30 metal framed construction + R-14 continuous rigid insulation	0.039	R-30 metal framed construction + R-10 continuous rigid insulation
White painted metal roof	0.044	R-19 metal framed construction + R-10 continuous rigid insulation	0.048	R-25 metal framed construction + R-6 continuous rigid insulation
Dark painted metal roof	0.033	R-30 metal framed construction + R-14 continuous rigid insulation	0.035	R-38 metal framed construction + R-10 continuous rigid insulation

Table 10 and Table 11 show other measures besides roof insulation that can be used for compliance. The three examples used in this analysis are 1) adding overhangs to shade the windows, 2) reducing interior lighting power, and 3) increasing the efficiency of the cooling system. Any one of these three measures provides compliance; it is not necessary to install all three. In each case, the roof is assumed to meet the prescriptive insulation requirement with a 0.051 U-factor.

These results show that exterior shades have a significant impact on reducing peak loads, and hence, a shorter overhang relative to the envelope trade-off method is adequate for compliance in case of the whole building approach.

Lighting power can be reduced by installing high efficiency lamps, low-energy ballasts, occupancy sensors and/or daylight sensors, or a combination of these.

In this example the baseline HVAC equipment is a packaged roof top unit with VAV controls and an EER of 9.5. Increasing the EER to 9.8 is required for the white metal roof to comply. For all other cases, an EER of 10.7 is required for compliance.

[36] Please note that these construction assemblies only serve to represent the minimum complying construction. Some of these may not be commonly used. Please refer to Appendix C to find a construction that is more commonly used and still satisfies the minimum U-factor compliance requirement.

Table 10: Shading, Lighting and HVAC Efficiency Compliance Alternatives for Office Building Example Using Whole Building Trade-off Method (Climate Zone 2)

	Any One of These Three Measures Achieves Compliance		
Roof Surface Type	*Overhang Projection Factor*[37]	*Lighting Power Density (W/sf)*	*Cooling Energy Efficiency Ratio (EER)*
T-24 Baseline	0.0	1.10	9.5
Light-colored metallic finish	0.5	1.00	10.7
Light-colored flouropolymer	0.1	1.05	9.8
Dark-colored flouropolymer	0.5	1.00	10.7

Table 11: Shading, Lighting and HVAC Efficiency Compliance Alternatives for Office Building Example Using Whole Building Trade-off Method (Climate Zone 13)

	Any One of These Three Measures Achieves Compliance		
Roof Surface Type	*Overhang Projection Factor*	*Lighting Power Density (W/sf)*	*Cooling Energy Efficiency Ratio (EER)*
T-24 Baseline	0.0	1.10	9.5
Light-colored metallic finish	0.5	1.00	10.7
Light-colored flouropolymer	0.1	1.05	9.8
Dark-colored flouropolymer	0.5	1.00	10.7

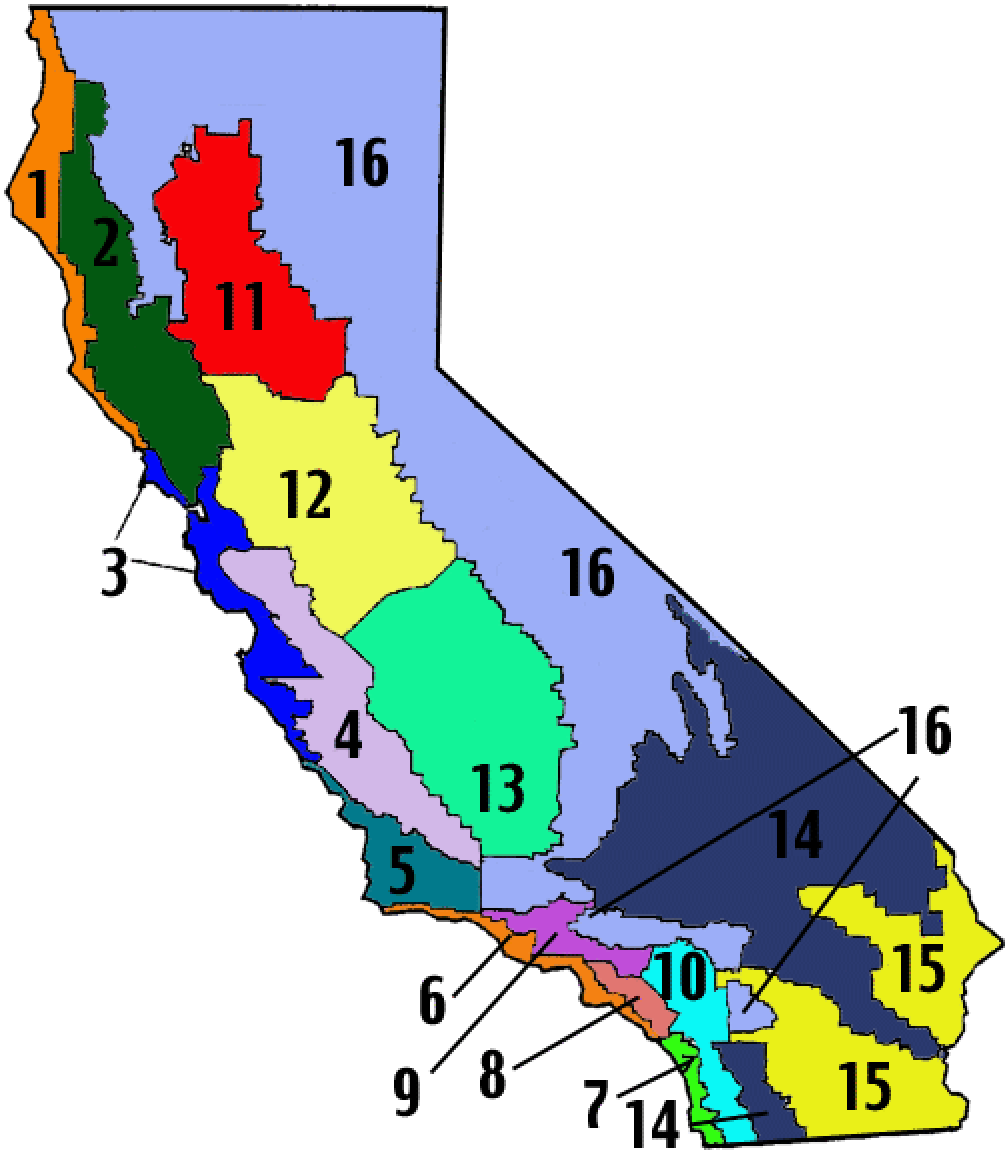
[37] Projection Factor = Horizontal Projection of Overhang ÷ Vertical Distance from Sill to bottom of Overhang

Appendix A: Glossary

Term	Definition
CLIMATE ZONES	are the 16 geographic areas of California for which the commission has established typical weather data, prescriptive packages and energy budgets. Climate zone boundary descriptions are in the document "California Climate Zone Descriptions" (July 1995), incorporated herein by reference. FIGURE 101-A is an approximate map of the 16 climate zones.
CONDITIONED FLOOR AREA	is the “conditioned floor area” as defined in Section 101 (b) of Part 6.
CONDITIONED FLOOR AREA (CFA)	is the floor area (in square feet) of enclosed conditioned space on all floors of a building, as measured at the floor level of the exterior surfaces of exterior walls enclosing the conditioned space.
CONDITIONED SPACE	is space in a building that is either directly conditioned or indirectly conditioned.
CONDITIONED VOLUME	is the total volume (in cubic feet) of the conditioned space within a building.
CONTINUOUS INSULATION	Insulation that is uninterrupted by framing members
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 Section 118 (i) that reduces heat gain through the roof.
DAYLIT AREA	is the floor area that is illuminated by daylight through vertical glazing or skylights as specified in Section 131(c). This includes area that has daylight controls and
EMITTANCE, THERMAL	is the ratio of the radiant heat flux emitted by a sample to that emitted by a blackbody radiator at the same temperature.
PROJECTION FACTOR	is the ratio of the depth of the overhang to the perpendicular distance between the sill of the window and the bottom of the overhang
REFLECTANCE, SOLAR	is the ratio of the reflected solar flux to the incident solar flux.
R-VALUE	is the measure of it’s the thermal resistance of insulation or any material or building component expressed in ft^2-hr ºF/Btu.See Thermal Resistance
SKYLIGHT	is glazing having a slope less than 60 degrees from the horizontal with conditioned or unconditioned space below.
SKYLIGHT AREA	is the area of the rough opening for the skylight.

SKYLIGHT TYPE	is a type of skylight assembly having a specific solar heat gain coefficient and U-factor whether glass mounted on a curb, glass not mounted on a curb or plastic (assumed to be mounted on a curb).
SOLAR HEAT GAIN COEFFICIENT (SHGC)	is the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space.
SOLAR REFLECTANCE	See *Reflectance.*
THERMAL EMITTANCE	See *Emittance.*
THERMAL RESISTANCE (R)	is the resistance of a material or building component to the passage of heat in (hr. x ft.^{2} x ºF)/Btu.
TIME DEPENDENT VALUATION (TDV) ENERGY	is the time varying energy caused to be used at by the building to provide space conditioning and water heating and for specified buildings lighting, accounting for the energy used at the building site and consumed in producing and in delivering energy to a site, including, but not limited to, power generation, transmission and distribution losses.
U-FACTOR	is the overall coefficient of thermal transmittance of a construction assembly, in Btu/(hr. x ft.^{2} x ºF), including air film resistance at both surfaces.
UNCONDITIONED SPACE	is enclosed space within a building that is not directly conditioned, or indirectly conditioned.
U-VALUE	See *U-factor*.
WINDOW AREA	is the area of the surface of a window, plus the area of the frame, sash, and mullions.
WINDOW TYPE	is a window assembly having a specific solar heat gain coefficient, relative solar heat gain, and U-factor.
WINDOW WALL RATIO	is the ratio of the window area to the gross exterior wall area.

Appendix B: Map of California Climate Zones



Climate Zone 2		Climate Zone 13	
LATITUDE = 38.40		LATITUDE = 36.80	
LONGITUDE = 122.70		LONGITUDE = 119.70	
AVG. TEMP. (F) (DRYBULB	57.3	AVG. TEMP. (F) (DRYBULB	63.8
AVG. TEMP. (F) (WETBULB	50.1	AVG. TEMP. (F) (WETBULB	53.6
AVG. DAILY MAX. TEMP(F)	71.9	AVG. DAILY MAX. TEMP(F)	77.3
AVG. DAILY MIN. TEMP(F)	45.3	AVG. DAILY MIN. TEMP(F)	51.5
HEATING DEG. DAYS (BASE 65)	2889.5	HEATING DEG. DAYS (BASE 65)	2227.5
COOLING DEG. DAYS (BASE 80)	0	COOLING DEG. DAYS (BASE 80	225.5

Appendix C: U-Factors for Roof and Wall Construction from ACM Appendix IV

The following information comes from Joint Appendix IV of the 2005 standards. The complete document is available from www.energy.ca.gov/title24. A new feature in the 2005 standards is that U-factors used for compliance must be taken from one of these tables. Custom U-factor calculations will no longer be permitted.

Table IV.5 –U-factors[38] of Metal Framed Rafter Roofs

Spacing	R-Value of Insulation Between Framing	Nominal Framing Size		Rated R-value of Continuous Insulation[2] R-0 A	R-2 B	R-4 C	R-6 D	R-7 E	R-8 F	R-10 G	R-14 H
16 in. OC	None	Any	**1**	0.325	0.197	0.141	0.110	0.099	0.090	0.076	0.059
	R-11	2x6	**2**	0.123	0.099	0.082	0.071	0.066	0.062	0.055	0.045
	R-13	2x6	**3**	0.115	0.093	0.079	0.068	0.064	0.060	0.053	0.044
	R-19	2x8	**4**	0.096	0.081	0.069	0.061	0.057	0.054	0.049	0.041
	R-21	2x8	**5**	0.093	0.078	0.068	0.060	0.056	0.053	0.048	0.040
	R-25	2x10	**6**	0.084	0.072	0.063	0.056	0.053	0.050	0.046	0.039
	R-30 [1]	2x10	**7**	0.079	0.068	0.060	0.054	0.051	0.048	0.044	0.038
	R-30	2x12	**8**	0.076	0.066	0.058	0.052	0.050	0.047	0.043	0.037
	R-38 [1]	2x12	**9**	0.071	0.062	0.055	0.050	0.047	0.045	0.042	0.036
	R-38	2x14	**10**	0.068	0.060	0.053	0.048	0.046	0.044	0.040	0.035
	Sprayed Foam or Cellulose Insulation[3]	2x6	**11**	0.099	0.083	0.071	0.062	0.058	0.055	0.050	0.041
		2x8	**12**	0.087	0.074	0.065	0.057	0.054	0.051	0.047	0.039
		2x10	**13**	0.077	0.067	0.059	0.053	0.050	0.048	0.044	0.037
		2x12	**14**	0.069	0.061	0.054	0.049	0.047	0.044	0.041	0.035
		2x14	**15**	0.064	0.057	0.051	0.046	0.044	0.042	0.039	0.034
24 in. OC	None	Any	**16**	0.322	0.196	0.141	0.110	0.099	0.090	0.076	0.058
	R-11	2x6	**17**	0.107	0.088	0.075	0.065	0.061	0.058	0.052	0.043
	R-13	2x6	**18**	0.099	0.083	0.071	0.062	0.058	0.055	0.050	0.041
	R-19	2x8	**19**	0.080	0.069	0.061	0.054	0.051	0.049	0.044	0.038
	R-21	2x8	**20**	0.076	0.066	0.058	0.052	0.050	0.047	0.043	0.037
	R-25	2x10	**21**	0.068	0.060	0.053	0.048	0.046	0.044	0.040	0.035
	R-30 [1]	2x10	**22**	0.063	0.056	0.050	0.046	0.044	0.042	0.039	0.033
	R-30	2x12	**23**	0.061	0.054	0.049	0.045	0.043	0.041	0.038	0.033
	R-38 [1]	2x12	**24**	0.055	0.050	0.045	0.041	0.040	0.038	0.035	0.031
	R-38	2x14	**25**	0.053	0.048	0.044	0.040	0.039	0.037	0.035	0.030
	Sprayed Foam or Cellulose Insulation[3]	2x6	**26**	0.081	0.070	0.061	0.055	0.052	0.049	0.045	0.038
		2x8	**27**	0.070	0.061	0.055	0.049	0.047	0.045	0.041	0.035
		2x10	**28**	0.061	0.054	0.049	0.045	0.043	0.041	0.038	0.033
		2x12	**29**	0.054	0.049	0.044	0.041	0.039	0.038	0.035	0.031
		2x14	**30**	0.049	0.045	0.041	0.038	0.036	0.035	0.033	0.029

[38] The U-Factors in this table take into account the degradation in overall resistance of batt insulation when it is compressed at the point of contact between the structural member and the roof, or when it is installed inside a cavity whose width is smaller than that of the insulation

Notes:

1 A higher density fiberglass batt is needed to provide adequate room for ventilation.

2 Continuous insulation shall be located at the ceiling or at the roof and be uninterrupted by framing.

3 Foamed plastic or cellulose insulation shall fill the entire cavity. Cellulose shall have a binder to prevent sagging. Verify that the building official in your area permits this construction, since there is no ventilation layer.

4. In climate zones 1 and 16 the insulating R-value of continuous insulation materials installed above the roof waterproof membrane shall be multiplied times 0.8 before choosing the table column for determining assembly U-factor.

This table contains pre-calculated U-factors for metal-framed rafter roofs where the ceiling is the air barrier. This construction assembly is similar to that covered by Table IV.2 except that metal framing members are substituted for the wood-framing members. The rafters may be either flat or in a sloped application. Insulation is typically installed between the rafters. With this construction, the insulation is in contact with the ceiling and there is typically a one-inch air gap above the insulation so that moisture can be vented. Whether or not there is an air space above the insulation depends on local climate conditions and may not be required in some building permit jurisdictions. The building official will need to waive the air gap requirement in the case of cellulose insulation or sprayed foam.

U-factors are selected from Column A of this table when there is no continuous insulation. When continuous insulation is installed either at the ceiling or at the roof, then U-factors from other columns may be selected. The continuous insulation is typically a rigid polystyrene or polyisocyanurate foam insulation, but can also include mineral wool or other suitable materials.

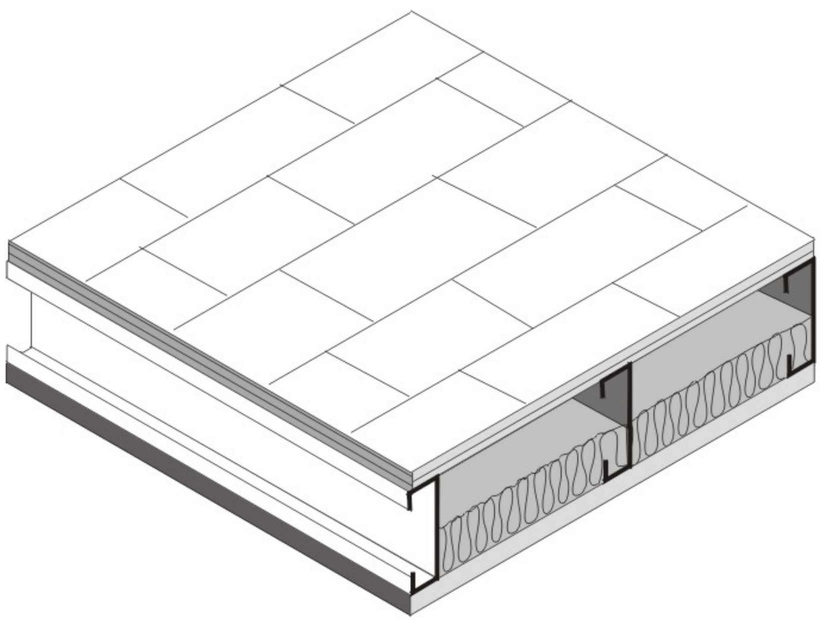


Figure IV.1 – Metal Framed Rafter Roof

When this table is used manually, the R-value of continuous insulation shall be equal to or greater than the R-value published in the continuous insulation columns. For instance if the insulation is R-3, the R-2 column shall be used. No interpolation is permitted when data from the table is used manually. CEC approved software, however, may determine the U-factor for any amount of continuous insulation and/or for unusual construction layers using Equation IV-1 and Equation IV-2.

Assumptions. These data are calculated using the zone calculation method documented in the 2001 ASHRAE Fundamentals. These calculations assume an exterior air film of R-0.17, asphalt shingles of R-0.44 (AR02), building paper of R-0.06 (BP01), ½” of plywood of R-0.63 (PW03), the insulation / framing layer, ½” gypsum of R-0.45 (GP01), and an interior air film (heat flow up diagonally) of R-0.62. The continuous insulation may either be located at the ceiling or over the structural deck. The thickness of framing members is assumed to be 3.50, 5.50, 7.25, 9.25, and 11.25 in. for 2x4, 2x6, 2x8, 2x10, and 2x12 nominal sizes. High-density batt insulation is assumed to be 8.5 in. thick for R-30 and 10.5 in thick for R-38. Framing spacing is 10 percent for 16 inches on center and 7 percent for 24 inches on center. Steel framing has 1.5 inch flange and is 0.075 inch thick steel with no knockouts. U-factors calculated using EZ Frame 2.0B.

Table IV.7 –U-factors[39] for Metal Building Roofs

Insulation System	R-Value of Insulation		Rated R-value of Continuous Insulation R-0	R-4	R-6	R-8	R-10	R-12	R-15	R-20	R-25	R-30
			A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Screw Down Roofs (no Thermal Blocks)[2]	None	**1**	1.280	0.209	0.147	0.114	0.093	0.078	0.063	0.048	0.039	0.032
	R-10	**2**	0.153	0.095	0.080	0.069	0.060	0.054	0.046	0.038	0.032	0.027
	R-11	**3**	0.139	0.089	0.076	0.066	0.058	0.052	0.045	0.037	0.031	0.027
	R-13	**4**	0.130	0.086	0.073	0.064	0.057	0.051	0.044	0.036	0.031	0.027
	R-19	**5**	0.098	0.070	0.062	0.055	0.049	0.045	0.040	0.033	0.028	0.025
Standing Seam Roof with Single Layer of Insulation Draped over Purlins and Compressed. Thermal blocks at supports.[2]	R-10	**6**	0.097	0.070	0.061	0.055	0.049	0.045	0.040	0.033	0.028	0.025
	R-11	**7**	0.092	0.067	0.059	0.053	0.048	0.044	0.039	0.032	0.028	0.024
	R-13	**8**	0.083	0.062	0.055	0.050	0.045	0.042	0.037	0.031	0.027	0.024
	R-19	**9**	0.065	0.052	0.047	0.043	0.039	0.037	0.033	0.028	0.025	0.022
Standing Seam Roof with Double Layer of Insulation.[4] Thermal blocks at supports.[2]	R-10 + R-10	**10**	0.063	0.050	0.046	0.042	0.039	0.036	0.032	0.028	0.024	0.022
	R-10 + R-11	**11**	0.061	0.049	0.045	0.041	0.038	0.035	0.032	0.027	0.024	0.022
	R-11 + R-11	**12**	0.060	0.048	0.044	0.041	0.038	0.035	0.032	0.027	0.024	0.021
	R-10 + R-13	**13**	0.058	0.047	0.043	0.040	0.037	0.034	0.031	0.027	0.024	0.021
	R-11 + R-13	**14**	0.057	0.046	0.042	0.039	0.036	0.034	0.031	0.027	0.024	0.021
	R-13 + R-13	**15**	0.055	0.045	0.041	0.038	0.035	0.033	0.030	0.026	0.023	0.021
	R-10 + R-19	**16**	0.052	0.043	0.040	0.037	0.034	0.032	0.029	0.025	0.023	0.020
	R-11 + R-19	**17**	0.051	0.042	0.039	0.036	0.034	0.032	0.029	0.025	0.022	0.020
	R-13 + R-19	**17**	0.049	0.041	0.038	0.035	0.033	0.031	0.028	0.025	0.022	0.020
	R-19 + R-19	**18**	0.046	0.039	0.036	0.034	0.032	0.030	0.027	0.024	0.021	0.019
Filled Cavity with Thermal Blocks[2, 5]	R19 + R-10	**19**	0.041	0.035	0.033	0.031	0.029	0.027	0.025	0.023	0.020	0.018

Notes:

1. A roof must have metal purlins no closer than 4 ft on center to use this table. If the roof deck is attached to the purlins more frequently than 12 in oc, 0.008 must be added to the U-factors in this table.
2. Thermal blocks are an R-5 of rigid insulation, which extends 1" beyond the width of the purlin on each side.
3. Multiple R-values are listed in order from outside to inside. First layer is parallel to the purlins, and supported by a system; second layer is laid on top of the purlins.
4. In climate zones 1 and 16 the insulating R-value of continuous insulation materials installed above the roof waterproof membrane shall be multiplied times 0.8 before choosing the table column for determining assembly U-factor.

The U-factors in this table are intended for use with metal building roofs. This type of construction is typical for manufacturing and warehouse facilities, but is used for other building types as well. The typical method of insulating this type of building is to drape vinyl backed fiberglass insulation over the metal purlins before the metal deck is attached with metal screws. With this method, the

[39] See footnote 38

insulation is compressed at the supports, reducing its effectiveness. The first part of the table contains values for this insulation technique. The second section of the table has data for the case when a thermal block is used at the support. The insulation is still compressed, but the thermal block, which generally consists of an 8 in. wide strip of foam insulation, improves the thermal performance. The third section of the table deals with systems that involve two layers of insulation.

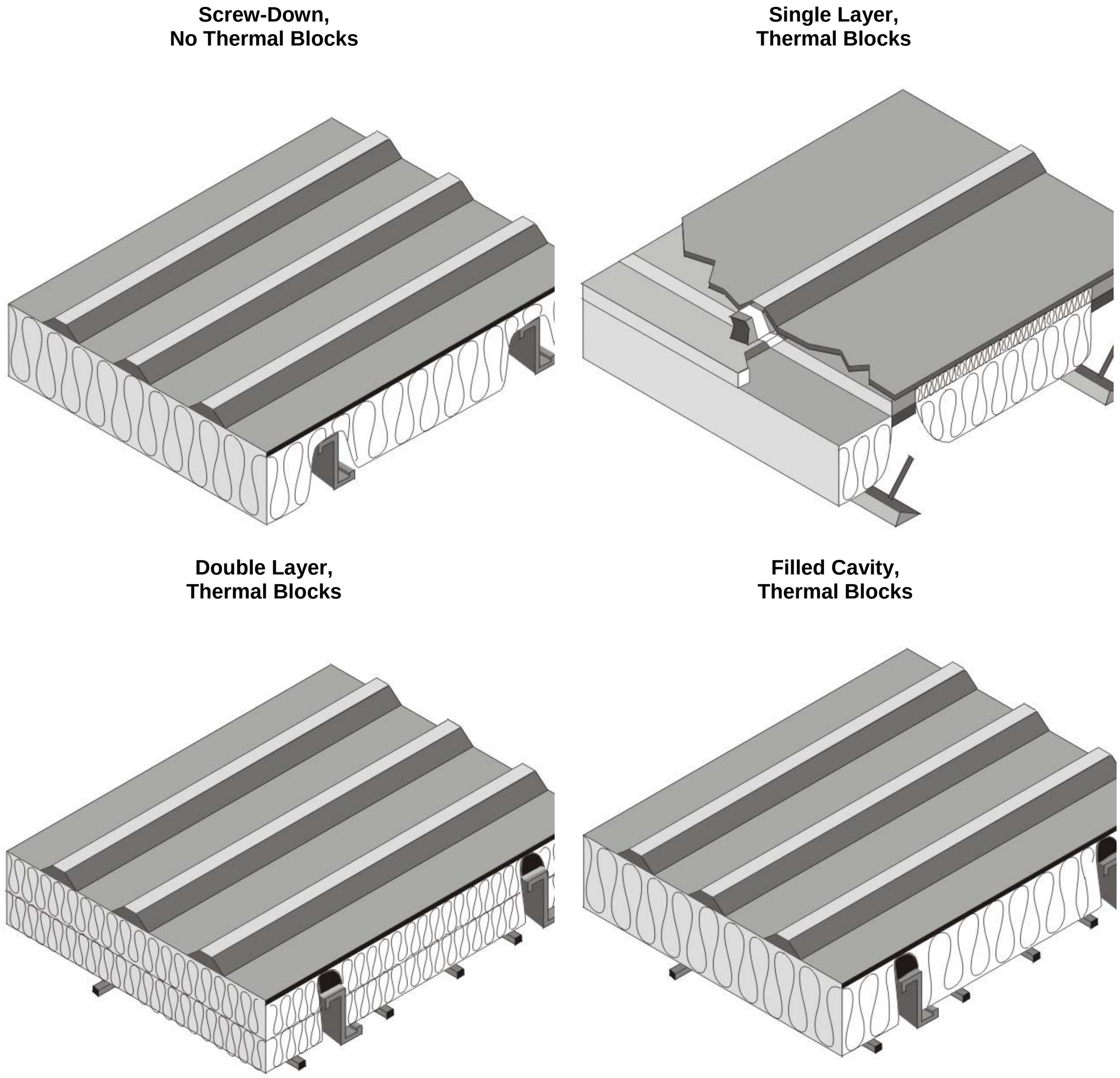


Figure IV.2 – Metal Building Roofs

For the majority of cases, values will be selected from column A of this table. Builders or designers may increase thermal performance by adding a continuous insulation layer between the metal decking and the structural supports. The continuous insulation is typically a rigid polystyrene or polyisocyanurate foam insulation.

When this table is used manually, the R-value of continuous insulation shall be equal to or greater than the R-value published in the continuous insulation columns. No interpolation is permitted when data from the table is used manually. CEC approved ACMs, however, may determine the U-factor for any amount of continuous insulation using Equation IV-1.

Assumptions. Data in Column A of this table is taken from the ASHRAE/IESNA Standard 90.1-2001, Appendix A. The data is also published in the NAIMA *Compliance for Metal Buildings*, 1997.

Table IV.11 – U-factors[40] of Metal Framed Walls

Spacing	Cavity Insulation R-Value:	Nominal Framing Size		Rated R-value of Continuous Insulation [2] R-0	R-2	R-4	R-6	R-7	R-8	R-10	R-14
				A	B	C	D	E	F	G	H
16 in. OC	None	Any	**1**	0.458	0.239	0.162	0.122	0.109	0.098	0.082	0.062
	R-11	2x4	**2**	0.224	0.155	0.118	0.096	0.087	0.080	0.069	0.054
	R-13	2x4	**3**	0.217	0.151	0.116	0.094	0.086	0.079	0.068	0.054
	R-15	2x4	**4**	0.211	0.148	0.114	0.093	0.085	0.078	0.068	0.053
	R-19[1]	2x6	**5**	0.183	0.134	0.106	0.087	0.080	0.074	0.065	0.051
	R-21	2x6	**6**	0.178	0.131	0.104	0.086	0.079	0.073	0.064	0.051
	R-19	2x8	**7**	0.164	0.123	0.099	0.083	0.076	0.071	0.062	0.050
	R-22	2x8	**8**	0.160	0.121	0.098	0.082	0.075	0.070	0.062	0.049
	R-25	2x8	**9**	0.158	0.120	0.097	0.081	0.075	0.070	0.061	0.049
	R-30[1]	2x8	**10**	0.157	0.119	0.096	0.081	0.075	0.070	0.061	0.049
	R-30	2x10	**11**	0.140	0.109	0.090	0.076	0.071	0.066	0.058	0.047
	R-38[1]	2x10	**12**	0.139	0.109	0.089	0.076	0.070	0.066	0.058	0.047
	R-38	2 x 12	**13**	0.124	0.099	0.083	0.071	0.066	0.062	0.055	0.045
	Foamed Plastic or Cellulose Insulation[3]	2 x 4	**14**	0.218	0.152	0.116	0.094	0.086	0.079	0.069	0.054
		2 x 6	**15**	0.179	0.132	0.104	0.086	0.079	0.074	0.064	0.051
		2 x 8	**16**	0.157	0.119	0.096	0.081	0.075	0.070	0.061	0.049
		2 x 10	**17**	0.138	0.108	0.089	0.075	0.070	0.066	0.058	0.047
		2 x 12	**18**	0.123	0.099	0.082	0.071	0.066	0.062	0.055	0.045
24 in. OC	None	Any	**24**	0.455	0.238	0.161	0.122	0.109	0.098	0.082	0.062
	R-11	2x4	**25**	0.210	0.148	0.114	0.093	0.085	0.078	0.068	0.053
	R-13	2x4	**26**	0.203	0.144	0.112	0.092	0.084	0.077	0.067	0.053
	R-15	2x4	**27**	0.197	0.141	0.110	0.090	0.083	0.076	0.066	0.052
	R-19[1]	2x6	**28**	0.164	0.123	0.099	0.083	0.076	0.071	0.062	0.050
	R-21	2x6	**29**	0.161	0.122	0.098	0.082	0.076	0.070	0.062	0.049
	R-19	2x8	**30**	0.153	0.117	0.095	0.080	0.074	0.069	0.060	0.049
	R-22	2x8	**21**	0.149	0.115	0.093	0.079	0.073	0.068	0.060	0.048
	R-25	2x8	**32**	0.147	0.114	0.093	0.078	0.072	0.068	0.060	0.048
	R-30[1]	2x8	**33**	0.146	0.113	0.092	0.078	0.072	0.067	0.059	0.048
	R-30	2x10	**34**	0.130	0.103	0.086	0.073	0.068	0.064	0.057	0.046
	R-38[1]	2x10	**35**	0.128	0.102	0.085	0.072	0.068	0.063	0.056	0.046
	R-38	2 x 12	**36**	0.115	0.093	0.079	0.068	0.064	0.060	0.053	0.044

[40] The U-Factors in this table take into account the degradation in overall resistance of batt insulation when it is installed inside a cavity whose width is smaller than that of the insulation and compressed as a result.

Spacing	Cavity Insulation R-Value:	Nominal Framing Size		Rated R-value of Continuous Insulation [2]							
				R-0	R-2	R-4	R-6	R-7	R-8	R-10	R-14
				A	B	C	D	E	F	G	H
	Foamed Plastic or Cellulose Insulation[3]	2 x 4	**37**	0.204	0.145	0.112	0.092	0.084	0.078	0.067	0.053
		2 x 6	**38**	0.167	0.125	0.100	0.083	0.077	0.071	0.063	0.050
		2 x 8	**39**	0.146	0.113	0.092	0.078	0.072	0.067	0.059	0.048
		2 x 10	**40**	0.128	0.102	0.085	0.072	0.068	0.063	0.056	0.046
		2 x 12	**41**	0.114	0.093	0.078	0.068	0.063	0.060	0.053	0.044

Notes

1. Higher density fiberglass batt is required in these cases.
2. Continuous insulation may be installed on either the inside or the exterior of the wall, or both.
3. Foamed plastic and cellulose shall fill the entire cavity. Cellulose shall have a binder to prevent sagging.

Table IV.12 – Properties of Hollow Unit Masonry Walls

						Partly Grouted with Ungrouted Cells					
			Solid Grout			**Empty**			**Insulated**		
Thickness	**Type**		**A**			**B**			**C**		
		1	U-factor	C-factor	HC	U-factor	C-factor	HC	U-factor	C-factor	HC
12"	LW CMU	**2**	0.51	0.90	23	0.43	0.68	14.8	0.30	0.40	14.8
	MW CMU	**3**	0.54	1.00	23.9	0.46	0.76	15.6	0.33	0.46	15.6
	NW CMU	**4**	0.57	1.11	24.8	0.49	0.84	16.5	0.36	0.52	16.5
10"	LW CMU	**5**	0.55	1.03	18.9	0.46	0.76	12.6	0.34	0.48	12.6
	MW CMU	**6**	0.59	1.18	19.7	0.49	0.84	13.4	0.37	0.54	13.4
	NW CMU	**7**	0.62	1.31	20.5	0.52	0.93	14.2	0.41	0.63	14.2
8"	LW CMU	**8**	0.62	1.31	15.1	0.50	0.87	9.9	0.37	0.54	9.9
	MW CMU	**9**	0.65	1.45	15.7	0.53	0.96	10.5	0.41	0.63	10.5
	NW CMU	**10**	0.69	1.67	16.3	0.56	1.07	11.1	0.44	0.70	11.1
	Clay Unit	**11**	0.57	1.11	15.1	0.47	0.78	11.4	0.39	0.58	11.4
6"	LW CMU	**12**	0.68	1.61	10.9	0.54	1.00	7.9	0.44	0.70	7.9
	MW CMU	**13**	0.72	1.86	11.4	0.58	1.14	8.4	0.48	0.81	8.4
	NW CMU	**14**	0.76	2.15	11.9	0.61	1.27	8.9	0.52	0.93	8.9
	Clay Unit	**15**	0.65	1.45	11.1	0.52	0.93	8.6	0.45	0.73	8.6

Appendix D: Glazing Costs

Glass Type	Installed Cost ($/sf)
Single Clear	$ 8.45
Single Tint	$ 9.13
Single High Perf Tint	$ 10.31
Single Reflective - Medium	$ 10.14
Single Reflective - High	$ 11.63
Laminated Clear	$ 17.62
Laminated Clear Low-e	$ 19.12
Double Clear	$ 13.55
Double Tint	$ 14.23
Double High Perf Tint	$ 15.41
Double Clr Low-e (VE 1-55)	$ 16.73
Double High Perf Tint Low-e (VE8-55)	$ 18.59
Double Clear Low-e2 (VE1-2M)	$ 16.73
Double High Perf Tint Low-e2 (VE8-2M)	$ 18.59