

DESIGN GUIDE

Thermal Design and Code Compliance for Cold-Formed Steel Walls

2015 Edition

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**American
Iron and Steel
Institute**



Steel Framing Alliance™

Thermal Design and Code Compliance for Cold-Formed Steel Walls 2015 Edition

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Acknowledgements and Limitations

This guide is an update of the *Thermal Design Guide for Exterior Walls* originally published in 1995 by the American Iron and Steel Institute (AISI) and revised in 2008. This updated guide addresses changes in codes and standards and incorporates information from recent research supported by the Steel Framing Alliance (SFA) and the Steel Stud Manufacturer's Association (SSMA). The author is Mark Nowak of M Nowak Consulting LLC. Appreciation is extended to the contributors of the previous guides who set the foundation for this document and to Nader Elhajj, Rick Haws, Jonathan Humble, Maribeth Rizzuto, and Tim Waite for their technical review.

Although the content in this guide is believed to be technically correct, users of any of the information herein are advised that the author, reviewers nor funding organizations make any guarantees as to the accuracy of any statements contained herein, nor offer any warranties, expressed or implied, relative to the use of the information in this report. Designers or other users should always check with their local building department prior to using the information in this report. Anyone using the information in this report does so at his or her own risk and assumes all liability for such use.

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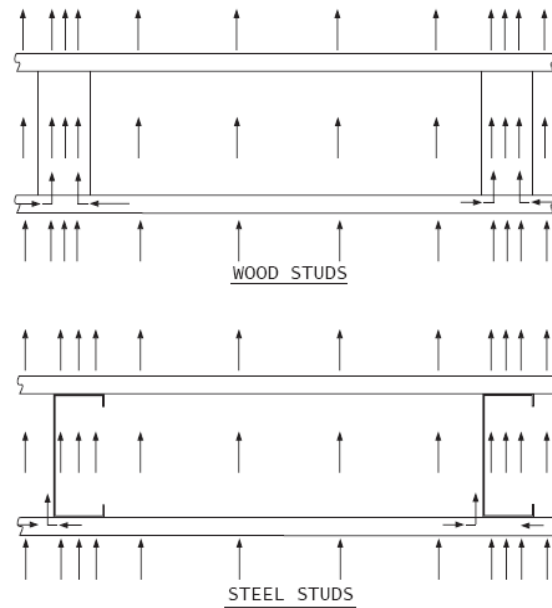
Chapter 1 - Background and Energy Code Overview

In the 1994-1995 timeframe, the American Iron and Steel Institute (AISI) sponsored ground-breaking research to develop recommendations for the design of walls constructed from cold-formed steel (CFS). The AISI *Thermal Design Guide for Exterior Walls* (Ref. 1) resulted from this work. A subsequent update in 2008 was published in acknowledgement that the framing environment had undergone significant changes since the 1990s.

Since the 2008 guide was published, many changes have occurred that affect the cold-formed steel industry. These changes include increased stringency of energy efficiency requirements in codes and standards and completion of research to better characterize the performance of CFS systems. Among the changes that dictate the need to once again update this guide are:

1. A move from simple wall assemblies with R-13 or R-19 cavity insulation to walls with cavity insulation plus continuous exterior insulation.
2. Expanded use of performance pathways for achieving code compliance.
3. Availability of new research that will allow more accurate calculations of an assembly's thermal performance.
4. An on-going expansion into load bearing CFS use in mid-rise buildings.

With any type of wall framing, heat flows directly through the cavity, the frame, and even laterally. Heat flow paths must be considered in determining the overall thermal characteristics of a wall assembly.



As the stringency of energy codes and standards has increased and resulted in greater thicknesses of continuous insulation (CI) on exterior walls, the ability to accurately determine thermal performance of CFS assemblies has increased in importance. Further, with the cost of assemblies rising due to CI requirements, alternative compliance options are becoming more advantageous. Thus, this document has three main objectives:

1. To provide the most up-to-date technical information on the thermal performance characteristics of the different types of CFS assemblies used in buildings, including specific methods for determining thermal performance based on the latest research.

2. To provide the information necessary for designers and builders to comply with requirements in the most recent major energy codes and standards.
3. To educate designers and builders on prescriptive and performance compliance alternatives, including approaches that can yield more cost-effective designs than the prescriptive solutions found in the major codes and standards.

Use of this Document

This document is designed to meet a variety of user needs. Designers or builders may need information on specific thermal properties of a wall system to comply with a local or state code or to determine their level of performance in a green rating system. Individuals interested in whole-building performance may need detailed information on simulation tools or calculation methods. Software developers will require the latest CFS thermal characteristics or calculation methods for various CFS assemblies. To provide this information, this document is set up in four chapters.

Chapter 1, Background and Energy Code Overview, describes the major codes and standards used in the United States and their general structure. Compliance paths are discussed including performance and prescriptive options. This chapter provides the user with a basic understanding of how energy codes are structured and the advantages and disadvantages of specific code compliance options. It is important to understand how to determine thermal performance of CFS assemblies, generally defined as the conductance or U-factor, in order to comply with the methods in various codes and standards. Thus, more-detailed examples of how to comply are provided in Chapter 4 following the discussion of U-factors and calculation methods in Chapters 2 and 3.

Chapter 2, Base Code U-factors for CFS Assemblies, contains a quick reference table of U-factors derived from Appendix Table A.3.3 of ASHRAE Standard 90.1 -2013 edition. This table is currently recognized in the most widely used energy codes and standards in the United States, although it is not applicable in California unless approved by the local code official. In addition to its use for default compliance U-factors in ASHRAE Standard 90.1 for CFS walls, these U-factors are also recognized in the IECC's commercial energy section. Currently, these are the only U-factors for CFS assemblies that have been approved by an ANSI-approved consensus process. For assemblies not provided in Chapter 2, the U-factor must be determined by another more detailed method as discussed in Chapter 3.

Chapter 3, Methods for Determining U-factors of CFS Walls, contains methods for determining U-factors of different CFS wall assemblies based on past and recent research. It provides information on various methods, their development, and how they should be applied to different wall types. This chapter is intended to address assemblies not covered in Chapter 3 and for those who wish to more accurately determine building performance beyond base code requirements.

Chapter 4, Code Compliance Options and Examples, provides a more detailed discussion on compliance options including examples showing how to use specific options and a discussion of designs that may be more economical than those typically found in prescriptive compliance paths.

This guide is not a substitute for legally adopted codes and standards. It must be used in combination with those documents. The reader is encouraged to become familiar with and have access to the *International Energy Conservation Code (IECC)* and *ASHRAE Standard 90.1-2013 Energy Standard for Buildings Except Low-Rise Residential Buildings* (Ref 2, 3). These documents are necessary to understand the concepts presented in this guide but their key requirements affecting CFS framing are not reproduced here.

Major Codes and Standards

There are literally thousands of jurisdictions in the United States that have adopted or enforce an energy code. Furthermore, many federal and state agencies have adopted their own standards for use in construction projects. However, the overwhelming majority of jurisdictions adopt a code based on either the IECC or ASHRAE Standard 90.1.

The IECC is produced by the International Code Council. A new version is released every three years with 2015 being the latest edition as of the time of this publication. The IECC can be purchased at www.iccsafe.org.

ASHRAE Standard 90.1 is produced by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. ASHRAE Standard 90.1 is published every three years, with 2013 the most recent edition as of the time of this publication. ASHRAE uses a continuous maintenance process that allows updates between the cycles. However, communities typically only adopt the full edition and not interim modifications. ASHRAE Standard 90.1 is referenced as an alternative compliance path in the IECC. It can be purchased from ASHRAE at www.ashrae.org.

The Office of Energy Efficiency and Renewable Energy within the U.S. Department of Energy tracks the adoption of energy codes and standards in the United States. Figures 1a and 1b illustrate the number of U.S. states where the IECC and/or ASHRAE Standard 90.1 have been adopted (from www.energycodes.gov/adoption/states). Canadian provinces adopt their own energy codes typically based on the National Energy Code of Canada for Buildings (NECB) (Ref. 4). ASHRAE Standard 90.1 with some Canadian-specific modifications is an alternative compliance path in the most recent NECB edition released in 2011.

Even in states that have their own code adoption process, energy codes tend to be based on the IECC or ASHRAE Standard 90.1 provisions. California is the most significant exception. The California energy provisions are developed by the California Energy Commission and divide the state into 16 climate zones versus eight in the IECC and ASHRAE Standard 90.1.

Except where specifically noted, when code requirements are discussed in this guide, they are based on the 2013 edition of ASHRAE Standard 90.1 and the 2015 edition of the IECC.

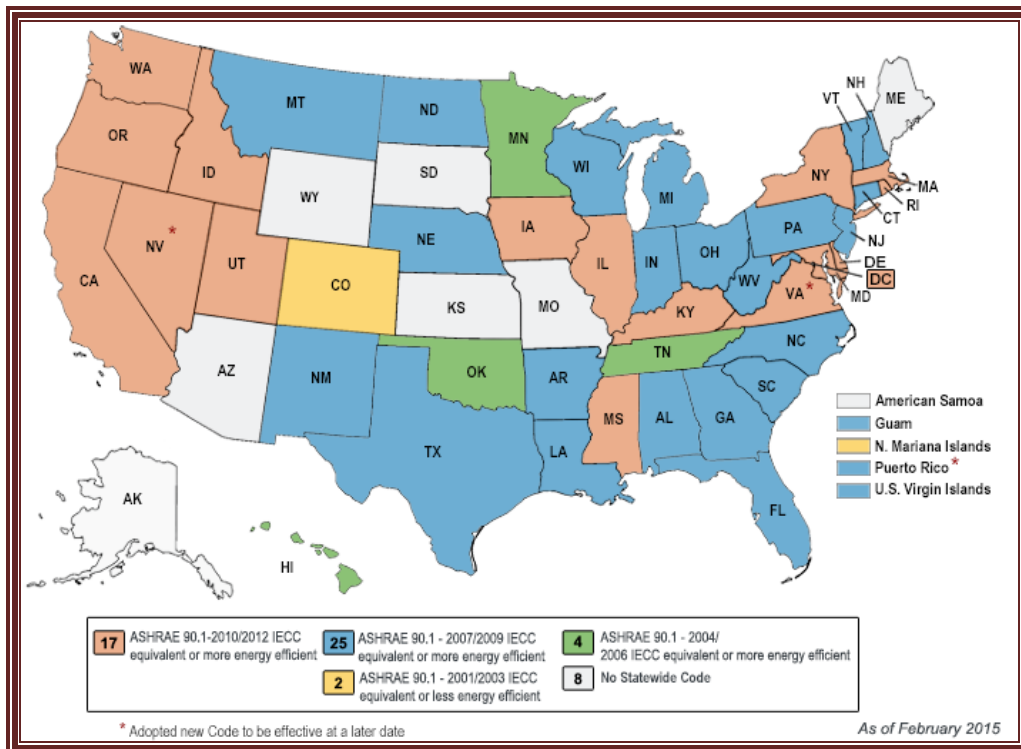


Figure 1a: Commercial energy code adoption in the United States (Source: U.S. Department. of Energy).

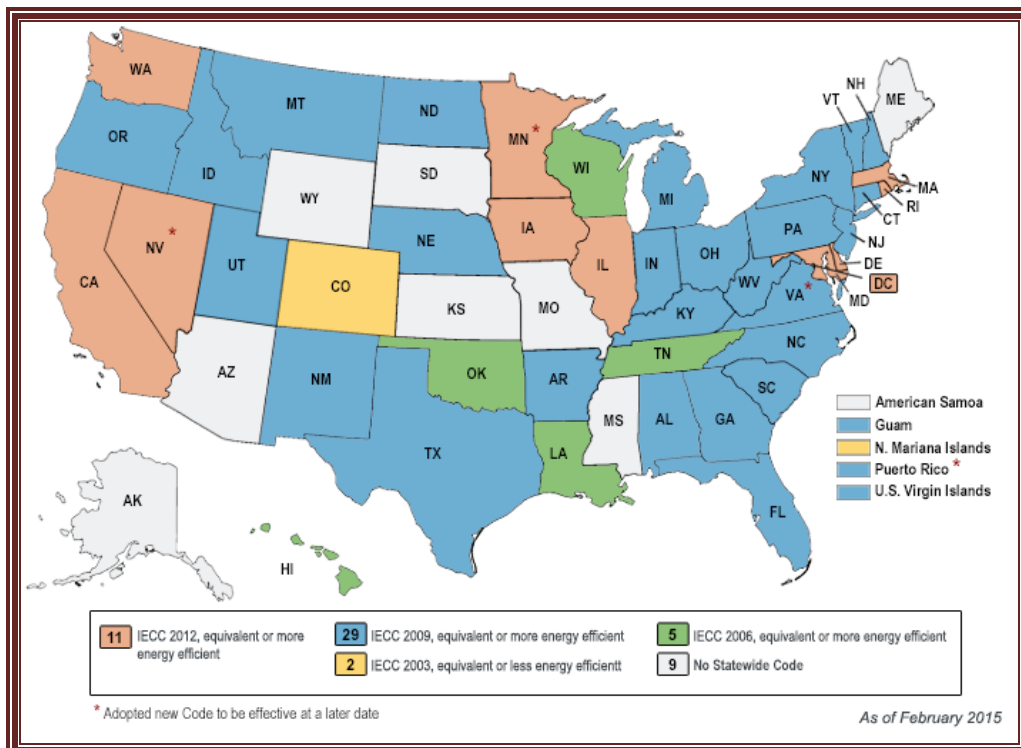


Figure 1. Residential energy code adoption in the United States (Source: U.S. Department. of Energy).

Climate Zones in ASHRAE 90.1 and the IECC have traditionally been numbered from 1 to 8 and are the same for all types of buildings (residential and commercial). However, there are subcategories of these climate zones for moist, dry, and marine conditions and a new tropical zone carved out of Climate Zone 1 in the IECC. The Climate Zone map used in both ASHRAE 90.1 and the IECC is shown Figure 2. A ninth zone labeled Climate Zone 0 was approved by the ASHRAE 90.1 committee to address extremely hot regions near the equator but this zone will not appear until the 2016 edition of the standard.

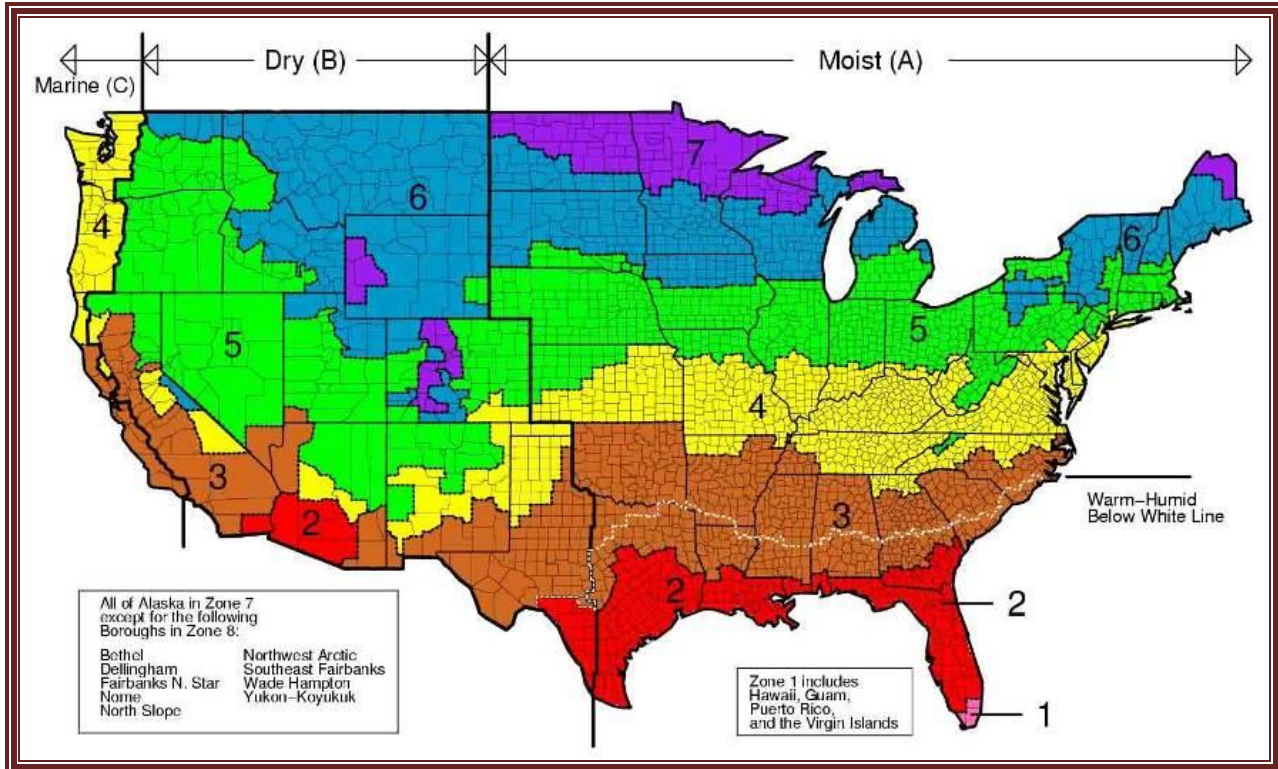


Figure 2. IECC Climate Zone Map (Source: U.S. Department of Energy).

Given the predominate reliance on ASHRAE Standard 90.1 and the IECC for commercial buildings, the discussion that follows is based on the content of these two documents. Note that the scope of ASHRAE Standard 90.1 is focused on commercial buildings. This includes residential occupancies in buildings four stories or more in height such as apartments, condominiums, dormitories, and hotels.

Single family homes are covered under the IECC in a separate chapter. Although the discussion here is focused on commercial and larger residential occupancies, the sections in this guide on methods for determining U-factors apply to all building types.

Compliance Paths

Both the IECC and ASHRAE Standard 90.1 accommodate multiple pathways towards compliance. Historically, codes have focused on options that are prescriptive in nature, although performance pathways that require building simulations are growing in

popularity and are included in ASHRAE Standard 90.1, the IECC, and most every other energy code or standard.

Prescriptive R-value path

The R-value option is the most often used compliance path due to its simplicity. For opaque parts of the envelope like walls, it requires a builder or designer to select insulation with a specific R-value from a table in the code. In order to use the prescriptive approach for the building envelope in either the IECC or ASHRAE Standard 90.1, one must first know the climate zone where the building is to be constructed (see Figure 2). Both the IECC and ASHRAE 90.1 give a choice of commercial or residential building types, although ASHRAE Standard 90.1 also includes semi-heated buildings as an option.

Again, it is important to stress that both documents include some residential buildings in their scope. For example, a hotel would be included in ASHRAE Standard 90.1 and the commercial chapters of the IECC. An apartment or other multi-family building would be a commercial building if it were over three stories in height. Low-rise residential buildings such as single family and townhomes are not in the scope of ASHRAE Standard 90.1 or the commercial sections of the IECC but are covered in the IECC residential sections.

Once the above information is known, one needs to look in the appropriate table (Table 5.5.1 through 5.5.8 in ASHRAE Standard 90.1, Table C402.1.3 for commercial buildings or Table R402.1.2 for low-rise residential in the IECC) to find the component being designed.

Continuous insulation used on exterior walls is commercially-available in several product types. Expanded polystyrene (EPS), extruded polystyrene (XPS), and polyisocyanurate are the most common products. Each has its advantages and disadvantages. EPS is generally the least expensive but it also has the lowest R-value per inch of the three product types. It generally has an R-value between 3.8 and 4.2 per inch depending on density and manufacturer. XPS is slightly more expensive than EPS but has an R-value closer to about R-5 per inch. Polyisocyanurate can have an R-value per inch in the range of R-6 to R-7, again depending on the manufacturer. It tends to be manufactured with a foil facing.



CI insulation (from left to right): XPS sheet, Polyisocyanurate sheet with foil facing, XPS over steel framed walls, EPS over concrete wall and foundation.

A CFS wall must be designed with R-values equal to or greater than those specified in the code. For example, a common IECC requirement for commercial buildings in Climate Zones 3 to 6 is R-13+7.5. In this case, the wall must have R-13 insulation in the

cavity between the studs and R-7.5 continuous insulation. The continuous insulation (CI) is most often placed on the exterior but can be on the inside of the wall as well. It typically consists of a semi-rigid foam board product.

Prescriptive U-factor path

Another variation of the prescriptive approach is the U-factor compliance path. Although U-factor requirements are located in the prescriptive section of the IECC and ASHRAE Standard 90.1, specifying a U-factor is really a performance approach applied to a specific component such as a wall.

In order to comply under the U-factor approach, a designer must be able to show that an assembly can achieve the U-factor in a given climate zone with the building type they are proposing to build. The U-factors in ASHRAE Standard 90.1 are located in the same tables as the R-value method (Tables 5.5.1 through 5.5.8). The IECC U-factors are in Table C402.1.4 for commercial buildings and Table R 402.1.4 for low-rise residential buildings. Using Climate Zone 4 criteria as an example to demonstrate the U-factor approach, Table C402.1.4 in the IECC would require a maximum U-factor of 0.064.

U-factors versus R-values: R-value is typically used to describe the thermal resistance of an individual material. For example, a typical batt insulation product in a 3-1/2 inch wall cavity would have an R-value of R-13 or R-15. The U-factor is the inverse of the R-value, or the thermal conductance of the material. U-factors can describe a specific product such as insulation but are generally used to describe the entire assembly, taking into account the impact of framing and other components in the assembly. A U-factor, in simple terms, is the inverse of the assembly R-value. Thus, a U-factor takes into account the wall's insulation plus the contribution of other components such as sheathing or gypsum wallboard, and also factors in the impact of a wall's framing members on overall thermal performance. As a U-factor decreases, an assembly is less efficient at conducting heat or more efficient at resisting heat loss.

When selecting the U-factor Prescriptive Method, the designer or builder must show how a given assembly U-factor is equal to or lower than the code specified maximum U-factor. This contrasts with the R-value prescriptive option where the labeled R-values of the insulation in the proposed assembly must be equal to or greater than those in the code requirements.

In the past, the U-factor compliance path has not been used as often as the R-value option because it requires a higher level of supporting documentation. Typically, it is employed for innovative systems that do not necessarily fit the description of the assemblies in the prescriptive tables from a code or standard.

Performance compliance path

A third pathway towards code compliance is the performance compliance option. This is sometimes called the simulated performance option or whole building simulation method. The performance option requires a computerized simulation tool to evaluate

the overall performance of the proposed design against the overall performance of a code minimum designed building, called the budget building design or standard reference design.

Envelope trade-off path

A fourth pathway allowed in many codes and energy standards is somewhat of a cross between performance and prescriptive. In the IECC residential chapters this is called the total UA alternative method. The UA of components comprising the thermal envelope (walls, floors, roof/ceilings, doors and fenestration) are determined by multiplying the surface area of each component by its assembly U-factor. This method is not part of the IECC commercial chapters. However, ASHRAE Standard 90.1 has a similar method called the Building Envelope Trade-off Option in Section 5.6.

The UA trade-off methods allow a designer or builder to effectively meet the U-factor requirements for the thermal envelope even though one or more parts of the building may be less stringent than the prescriptive values listed in a code. Deficiencies in one part of the building can be made up by exceeding requirements elsewhere in the building.

For residential buildings in the IECC (Section R402.1.4), UA calculations are performed by taking the U-factor of an assembly multiplied by the area (A) of that assembly to arrive at individual UA values for each component (walls, floors, roofs). The component UA values are summed to obtain a whole-building or total UA, which is then compared to the total UA for that type of building calculated from the minimum prescriptive code requirements.

Trade-off calculations in ASHRAE Standard 90.1 for larger residential and commercial building are more complex than for the smaller residential buildings in the IECC residential chapters. Fortunately, many software programs developed for the simulated performance option can be used to conduct a UA trade-off analysis. See the section called “Simulation Tools” in Chapter 4 for examples of available software.

Which method should be used?

From the various methods described above, there are advantages and disadvantages with each of the presented pathways for code compliance. There is no one method that will guarantee the most thermally-efficient design. The performance options offer the most flexibility, but are more complex to use than other approaches. The R-value prescriptive method by component is the most straightforward way to design a building, but it does not always lead to the most cost-effective assembly.

The U-factor method requires data that is not always found in energy codes so there is some extra burden of proof that the designer must meet. Fortunately, ASHRAE Standard 90.1 has some U-Factors in Appendix A for typical CFS assemblies. These U-factors are also recognized in the IECC. However, depending on the designer objectives and the type of assembly, the ASHRAE Standard 90.1 appendix values may not be as accurate as desired.

Later sections of this document provide more detailed information on determining U-factors for various uses. However, users are always advised to check with local code officials before using any U-factors not found directly in the pages of the applicable code or standards. As mentioned previously, some states such as California have their own values that are permitted to be used for compliance purposes or have them embedded into approved software.

Chapter 2 - Base Code U-factors for CFS Assemblies

R-values and U-factors are the primary thermal properties necessary for a designer, code official or builder to check compliance with energy codes, standards, and green building programs. These characteristics are also necessary for estimating heat loss and overall energy use in a building.

When a code specifies a prescriptive R-value for insulation that must be met, one simply compares the R-values of the wall cavity insulation and any exterior continuous insulation on the wall assembly to those values in the code or standard. The proposed wall insulation R-value total must be equal to or greater than the R-values listed in the code.

The situation becomes more complex when a code or standard specifies a U-factor for the entire wall assembly versus an R-value just for the insulation.

Table 1 contains the U-factors and R-values corresponding to the requirements in the IECC and ASHRAE Standard 90.1 for the most common CFS wall assemblies for commercial and residential buildings with four or more stories. The values were derived based on assumptions and a calculation procedure used to derive the U-factors in ASHRAE Standard 90.1 Table A.3.3.3.1.

Table 1 is intended to be a quick reference guide for values that should be acceptable for any CFS wall assembly being designed under the 2013 ASHRAE Standard 90.1 edition or the 2015 IECC. Table 1 is not comprehensive but rather addresses the most common combinations of insulation. For detailed discussions on the calculation methods used to determine these U-factors and alternative approaches for other insulation packages or more complex situations, see Chapter 3 of this guide.

The U-factors in Table 1 may be used for any type of building (i.e., commercial or residential) covered by the IECC commercial Chapters or ASHRAE Standard 90.1.

The values in Table 1 were calculated following a procedure used by the envelope subcommittee overseeing the American Society of Heating, Refrigeration, and Air Conditioning Engineers' (ASHRAE) 90.1 standard for energy efficiency. This method includes the impact of framing members on the wall assembly's thermal performance by applying a factor to the cavity insulation to account for the steel studs that pass through the assembly.

Table 1. Recommended U-factors for various combinations of insulation.

	1.5" x 3.5" or 3-5/8" Stud Depth with R-13 cavity insulation		1.5" x 5.5" or 6" Stud Depth with R-19 cavity insulation	
Continuous Insulation R-Value	Assembly U-factor at 16 inch stud spacing	Assembly U-factor at 24 inch stud spacing	Assembly U-factor at 16 inch stud spacing	Assembly U-factor at 24 inch stud spacing
None	0.124	0.108	0.109	0.094
R-3.8	0.085	0.077	0.078	0.069
R-5	0.077	0.070	0.071	0.064
R-7.5	0.064	0.060	0.060	0.055
R-10	0.055	0.052	0.052	0.048
R-12.5	0.049	0.046	0.046	0.043
R-15.6	0.042	0.040	0.041	0.038
R-17.5	0.039	0.037	0.038	0.036
18.8	0.037	0.036	0.036	0.034

It is important to understand that use of Table 1 may slightly under or overestimate thermal characteristics for a given assembly. The methodology that it is based on is geared toward code compliance – the assembly assumptions are intended to represent all CFS walls even though in reality an individual wall may vary in terms of claddings, framing factor, steel thickness, and other characteristics.

Although the method used in ASHRAE Standard 90.1 is the only calculation procedure that has passed through a consensus process, it is not the only available method for calculating thermal properties of CFS assemblies. The method provides a U-factor that takes into account that there are a variety of different CFS wall assemblies but that the ones chosen for this method are viewed as acceptable to represent the broad range of walls. This is acceptable for a code since the code is really an index of performance and not an exact measurement of energy use. In reality, there are often times when a more definitive U-factor is desired. Chapter 3 provides more detailed information on other methods for specific assembly types.

Chapter 3 - Methods for Determining U-factors of CFS Walls

The development of current theory on thermal calculations and tests for CFS assemblies goes back into the early 1990s when steel framing began to receive attention as a possible substitute for wood framing in the residential market. Prior to that timeframe, most jurisdictions did not adopt and/or enforce energy codes. Those that did usually limited requirements for CFS to whatever was required for wood cavity wall assemblies, such as R-11 or later R-13 batt insulation. Any thermal calculations that were performed relied on a conservative “zone method” described in ASHRAE’s Handbook of Fundamentals (Ref. 5).

The framing factor is the area in a wall that is taken up by the framing, including studs, tracks, headers, jambs, and all other framing. It is typically expressed as a percent or fraction of the framing relative to overall wall (or floor or ceiling) area. Typical wall framing factors run from about 11% to as high as 25%. Framing factor is just one variable that is important to the overall thermal performance of a steel stud wall system. Recent research suggests that with steel studs, the framing factor is not as critical in determining the U-factor as in other framed walls. Mainly this is due to the way in which steel is oriented and its location near openings when higher amounts of steel are used. However, many codes and simulation programs still place a heavy emphasis on the framing factor. The framing factor has and continues to be an issue of debate in codes and standards deliberations. The actual framing factor taken from construction plans can be higher or lower than the assumptions used in a code.

AISI sponsored the first large-scale hot box tests of CFS wall assemblies to determine a more accurate method for U-factor determinations. The test results led to the publication of the 1995 AISI Thermal Design Guide and the “modified zone method” for calculating U-factors of walls with exterior continuous insulation. The method was never integrated into codes and standards.

It is important to note that the test data reported in the 1995 *Thermal Design Guide* was limited to clear wall assemblies. A clear wall assembly typically has one top track, one bottom track, and studs spaced at 16 or 24 inches on center. This results in a “framing factor” (see sidebar), of about 11% for 24 inch stud spacing and 14% for 16 inch stud spacing.

Although a clear wall assembly is a good assumption for some wall systems such as blank walls (with little or no openings) and many

curtain walls, it is not usually representative of load-bearing CFS wall assemblies.

The best way to calculate the U-factor of a CFS wall will depend on a number of variables. Not only is it important to understand the requirements of the various codes and standards but it is also important to understand your own objectives. Is the goal to simply meet the code requirements or is it a more economical design? Or is the goal to estimate building energy use as close as possible? Table 2 shows the various objectives and wall types that a U-factor calculation can be based upon.

Table 2. U-factor determination options based on objectives and wall type.

Wall type				
Objective	Clear wall or with framing factor less than about 16%	Structural framing with framing factors up to about 25%	Empty cavity wall (no cavity insulation)	Systems with framing factors above 25% or with large areas of thermal bridges
Minimum code compliance (current IECC or 90.1)	ASHRAE Standard 90.1 Appendix A U-factors* or path correction calculation method or hot box test results	ASHRAE Standard 90.1 Appendix A U-factors* or path correction calculation method or hot box test results	ASHRAE Standard 90.1 Appendix A U-factors or hot box test results	ASHRAE Standard 90.1 Appendix A U-factors* or path correction calculation method or hot box test results
More accurate designs than allowed or mandated by code	Modified Zone Method with actual assembly component R-values	Path correction calculation adjusted to reflect higher amounts of framing or hot box test results	Finite element modeling or hot box tests or engineering judgment	Finite element modeling or hot box tests or engineering judgment
*The U-factors in ASHRAE Standard 90.1 Appendix A are mandatory in that standard unless approved by the code official. They are based on a path calculation method (also in the 2015 IECC) with specific assumptions for the siding and interior/exterior coverings. Correction factors (Fc) are applied to the section that contains the studs and cavity insulation. The calculation method using correction factors has been called different names over the years including the path correction method and the parallel path method. For the purposes of this guide, the term “path correction calculation method” is used.				

Table 2 takes into account recent hot box testing of 21 CFS wall assemblies conducted in the 2012-2011 timeframe by Oak Ridge National Laboratory (ORNL) and a subsequent analysis of those test results in 2013 (Ref. 6 and 7). The analysis report demonstrates that the U-factors in ASHRAE Standard 90.1 Appendix A for walls with 16 inch stud spacing are generally within the error associated with hot box tests. Thus, the ASHRAE Standard 90.1 U-factors can continue to be used as a conservative

representation of “average” CFS wall construction, taking into account that there are a wide variety of CFS wall types with varying amounts of framing.

Table 2 also recognizes that there are always opportunities to refine U-factors to better match specific assemblies that may perform better or worse than the “typical” assemblies often used for compliance in codes and standards. Although some would be concerned that codes and standards rely on “typical” conditions, it is important to keep in mind that energy codes are more of a performance index than predictors of exact energy use in a building. As the index is improved, all buildings will be improved.

Codes cannot address all possible scenarios in their prescriptive requirements and solutions. Thus, the standard set in energy codes reflects a reasonable level of performance taking into account a broad number of variables. This sometimes leads to uneven application of requirements. For example, although fasteners are not specifically mentioned in the assembly descriptions used to derive the ASHRAE Standard 90.1 Appendix A U-factors for metal stud walls, the U-factors are derived from test data that included assemblies with fasteners. The assumptions stated in the same appendix of Standard 90.1 for the parallel path method used to derive U-factors for wood framed walls with CI does not include fasteners in the CI and their impact is not included in the published U-factors.

Research on wood walls with continuous insulation suggests that the presence of fasteners will reduce the overall whole-wall R-value between 4.1% and 12% (Ref. 8). The impact is higher at thicker levels of continuous insulation than at thinner levels, suggesting that most of the impact occurs within the continuous insulation layer (i.e., the impact on cavity insulation is much less). Recent research sponsored by the CFS industry showed fasteners to have an impact of about 14% on a similar assembly with and without fasteners, although there was only one direct comparison of this effect (Ref. 7). More work is necessary in this area to develop an equitable method to address fastener impact across all materials.

Determining Thermal Characteristics for Code Compliance

This section discusses some basic terminology necessary to understanding the available methods for determining CFS wall U-factors and then discusses those methods in general terms. It then provides recommendations specific to different types of walls with more detailed information on U-factors or how to calculate them.

Terminology

Effective R-value. The thermal resistance of an entire assembly as opposed to just the R-value of the cavity insulation. The term “effective” is often used interchangeably with the terms “composite,” “whole-wall,” or “assembly” R-value. In each case, it is a measure of the overall thermal performance of the wall, floor, or ceiling taking into account all components of the assembly.

U-factor. In simple terms, a U-factor is the inverse of an R-value of an individual material or of the effective R-value of an assembly. Thus, U-factor can be used to describe the thermal conductance of an individual material such as insulation or the

overall conductance of an assembly. In this report, it is used to represent the thermal conductance of an assembly unless otherwise noted.

Parallel Path - A calculation method whereby multiple “paths” through assemblies having materials with distinctly different thermal resistance characteristics are assessed separately and then weighted according to their respective areas to determine a composite U-factor representing the entire wall. As an example, a separate path may be taken through the center of the cavity in a framed wall and another through the path that contains the studs. A parallel path calculation is typically used for wood framing. With metal studs, a similar approach has been used with a single path using correction factors to account for the impact of metal on the cavity insulation.

Isothermal Planes – This method of calculating U-factors also recognizes that materials can have very different levels of thermal resistance. The assembly is divided into layers or planes that are then combined in a single pathway to describe the thermal characteristics of the assembly. An important assumption with this method is that the temperatures are the same across the surface of each plane. It is primarily used with masonry or concrete assemblies.

Zone Method(s) – Zone Method calculations applied to a stud wall are a type of parallel path method. However, adjustments are made to the width of members that differ from the other parts of the assembly. For example, a theoretical zone is determined that represents the path occupied by a metal component in a wall. The area of this path is then weighted and combined with the thermal characteristics determined for the remaining pathway through the cavity area and its components. For steel framing, the Modified Zone Method was developed in the mid-1990s in recognition that the conventional Zone Method was too conservative.

The following sections provide more detailed guidance on how to apply different methods to specific CFS wall assemblies.

There are at least three options to determine the U-factors for a CFS framed wall assembly – the Path Correction Calculation Method, the Modified Zone Method, and wall assembly tests. The Parallel Path Method used for wood framing, the Isothermal Planes Method, and the conventional Zone Method should not be used for CFS assemblies. They are discussed above for information purposes only.

Path Correction Calculation Method for Basic Code Compliance

This method is a straightforward calculation approach employing correction factors applied to the section of the assembly that contains the cavity insulation and framing members. It has been used or recognized in various national model codes and standards including the 2015 IECC, ASHRAE 90.1, and ASHRAE Standard 90.2 -2007 for low rise residential buildings.

The IECC, ASHRAE Standard 90.1, and ASHRAE Standard 90.2 each rely on an approach with the following equations for wall assemblies:

Equation 1

$$U_w = 1/[R_s + (R_{ins} \times F_c)]$$

Where:

U_w = U-factor of CFS wall corrected for impact of CFS members

R_s = R-Value of all elements in the path through the wall excluding the framing and the cavity insulation (i.e., R-values of the gypsum board, inside and outside air films, sheathing, and exterior continuous insulation if present). See Appendix A of this document for R-values of common materials.

R_{ins} = R-value of the cavity insulation

F_c = Correction factor from Table 3

Table 3. Correction factors for various stud depths and cavity insulation R-values.

Stud depth*	Spacing	Cavity R	Fc
3.5	16 oc	13	0.46
3.5	24 oc	13	0.55
3.5	16 oc	15	0.43
3.5	24 oc	15	0.52
6	16 oc	19	0.37
6	24 oc	19	0.45
6	16 oc	21	0.35
6	24 oc	21	0.43

* A 3-5/8 stud may be used interchangeably with the 3.5 inch stud. Likewise, the Fc values for 6 inch studs may be applied to 5.5 inch studs.

Table 1 from Chapter 2 of this report contains U-factors for common assemblies that were calculated according to Equation 1 using Table 3 correction factors, along with the assumptions for R-values of components as shown in Table 4. This approach is applicable to assemblies where the basic objective is minimal compliance with the IECC or ASHRAE Standard 90.1. Table 1 entries are based on clear wall assembly hot box tests, although they are somewhat conservative for those assemblies because the test assemblies contained fasteners that are not typically considered in calculations for other materials.

Table 4. Assumptions for wall components outside of the cavity.

Component	R-value
Exterior air film	0.17
Stucco	0.08
5/8 inch exterior gypsum sheathing	0.56
5/8 inch interior gypsum board	0.56
Interior air film	0.68

Path Correction Calculation Method (higher framing factors)

As indicated earlier in this guide, the framing factors used in codes and standards are not uniform. California, for example, uses framing factors in the mid 20s (expressed as a percentage), whereas, ASHRAE Standard 90.1 Appendix A includes methods based on clear wall U-factors.

Based upon recent hot box testing, there is very little difference in U-factors with different framing factors, at least in the range of framing factors believed to represent typical construction. An analysis of the ASHRAE Standard 90.1 Appendix A U-factors showed that they tend to fall within the error associated with hot box tests conducted at higher framing factors (Ref. 7). Thus, the U-factors in ASHRAE Standard 90.1 Appendix A are still recommended in Chapter 2 of this guide as the primary source of thermal performance characteristics for cold-formed steel wall framing.

In some cases, it may be necessary or desired to reflect the performance of walls with higher framing factors. To address these cases, use of the hot box tests conducted in 2011 and 2012 were analyzed by the Steel Framing Alliance (Ref. 7) to develop correction factors for a path correction calculation method for walls with higher framing factors than originally assumed for the calculation methods. However, the use of this or any proposed method should always be approved by the code official before it is used for code compliance.

The 2011-2012 testing focused on walls with slightly over 23% framing factor. This is similar to a wood-framed wall with a framing factor of about 25%, due to the use of a single top track with steel framing versus double top plates with wood framing. The 25% is typically recognized as the default framing factor for wood framing. There is no typical default for steel framing at this point, although the framing factors for wood are often used as a baseline for other framing materials.

In order to determine the assembly R-value for a CFS assembly with 23 to 25% framing factor, new correction factors need to be applied to the cavity insulation to account for the increased framing.

Equation 1 is still applicable to walls with higher framing factors. However, the correction factors (F_c) should be derived from Equation 2. F_c values for common insulation values are pre-calculated in Table 5.

EQ. 2 $F_c = 0.6678 - 0.019 \cdot R_{cav}$ (Ref. 7)

Where:

F_c = factor to be applied to cavity insulation R-value

R_{cav} = R-value of cavity insulation

Table 5. Correction factors for 23%-25% framing factor walls for common insulation levels.

Cavity R-value	Cavity insulation correction factor (F_c)
13	0.42
15	0.38
19	0.31
21	0.27

The following limitations apply to Equation 2 and the factors in Table 5:

1. Their application is limited to walls with studs no deeper than 6 inches.
2. They should only be applied to fairly conventional assemblies, i.e., walls with C-shaped studs filled with cavity insulation and continuous insulation on either side.
3. They should be limited to assemblies having between R-3 and R-12 continuous insulation.
4. They should not be applied when there is zero continuous insulation (CI), or the cavity is empty.

For assemblies with CI R-values of R-12 or higher or less than R-3, and for assemblies without cavity insulation, hot box test results as shown below can be used for design of buildings with high framing factors.

Hot box Test Results

Hot box tests of wall assemblies are conducted in accordance with ASTM 1363. Testing sponsored by EIMA and SFA at Oak Ridge National Laboratory (ORNL) was conducted in 2010 and 2011. The assemblies contained approximately 23% framing area, roughly equivalent to a wood-framed wall with 25% framing.

For walls with cavity insulation and up to about 25% framing factor, the ORNL test results as provided in Table 6 should be acceptable under the IECC, provided the walls

are of similar construction in terms of cladding and other components or modified accordingly (see later examples). They may also be used in various green programs or advanced energy rating programs, or as more accurate representations of CFS walls for performance modeling.

As described previously, the F_c values for calculations using Equation 2 are not valid when the CI is R12 or higher or less than R-3. For assemblies outside of this range, the U-factors from hot box tests results in this section may be used for higher framing factor walls.

If a specific assembly is not shown in Table 6, an estimate of the U-factor can be made by adding or subtracting the value of continuous insulation from a similar tested assembly. In fact, this approach is specifically recognized in the 2015 IECC. Corrections can only be made to components outside of the cavity and when the cavity insulation is the same for the tested assembly and the assembly for which the U-factor is to be estimated. For example, if the U-factor of an assembly with R-13 + R-17 is desired but the only available test result is from a wall with R-13 + R15, the following approach can be used:

1. Divide 1 by the U-factor for the R-13+15 assembly (i.e., determine the reciprocal). This yields a total or assembly R-value for the assembly.
2. Determine the difference between continuous insulation on the R-13+ 15 and R-13 +17 assemblies. In this case, the difference is R-2 (17-15).
3. Add the difference from Step 2 to the assembly R-value from Step 1. This is the estimated assembly R-value for the R-13+17 wall.
4. Divide 1 by the R-value from Step 3 (i.e., determine the reciprocal) to obtain the U-factor for the R13+17 wall.

Note that the tested assemblies in Table 6 do not contain claddings except for the two walls that had a stucco finish. The R-value of the stucco is insignificant (less than R-0.1) and can be ignored. Further, a specific proposed wall may have interior or exterior sheathing that is different than the tested assemblies. These issues can be addressed by making the appropriate modifications in Step 3 of the example above by either adding or subtracting the appropriate R-value of different sheathings or claddings. Table 6 entries include the R-value that is provided by interior and exterior air films - these should not be added to the assemblies. For R-values of common construction materials, see Appendix A.

Although the IECC allows the R-value of components outside of the cavity to be added or subtracted from the results of the hot box test, the assembly within the cavity must be identical to the tested assembly if using the hot box test results for code compliance. This includes the framing members. Thus, Table 6 includes the specific stud designations as tested.

Table 6. Tested and adjusted U-factors and R-values CFS wall assemblies.

All walls have 23% framing factor				Adjusted to reflect labeled CI R-value*	
Stud	Sheathing	Cavity R-value (labeled)*	CI or Sheathing R-value (labeled)*	Overall R-value	Overall U-factor
350S162-43	3.0-inch EPS	13.0	12.0	18.0	0.056
350S162-43	0.75-inch & 3.0-inch EPS	13.0	15.0	19.8	0.051
350S162-43	0.5-inch OSB	15.0	0.5	7.3	0.137
350S162-43	2.0-inch EPS	0	8.0	9.5	0.105
350S162-43	2.0-inch XPS	0	10.0	12.3	0.081
550S162-43	0.5-inch OSB	21.0	0.5	7.4	0.135
550S162-43	0.5-inch XPS	21.0	3.0	10.3	0.097
Assemblies in shaded entries below relied on adhesives to attach CI versus screws for assemblies above					
350S162-43	R10 CI plus R-0.5 gyp.	0	10.0	13.0	0.077
350S162-43	R16 CI plus R-0.5 gyp.	0	16.0	18.8	0.053
550S162-43	R10 CI plus R-0.5 gyp.	0	10.0	13.2	0.076
550S162-43	R16 CI plus R-0.5 gyp.	0	16.0/13.9	18.8	0.053

* Consistent with U.S. Federal Trade Commission regulations, the tested values of components were within 10% of the labeled value. The overall U-factor and R-values were adjusted to reflect the labeled R-value of the CI layers. A similar correction is not possible for the cavity insulation, although this impact would be very small.

Example 1: Application of Table 6 for basic code compliance.

A maximum U-factor of 0.052 is required for a metal framed wall in a hotel in Climate Zone 7 under the IECC. The second assembly from the top in Table 6 with R-13+15 has a U-factor of 0.051. This assembly meets the requirement without the need to consider the R-value of cladding.

Example 2: Application of Table 6 under the IECC when exact match is not available. The 2015 IECC allows corrections to be made to a hot box test result for components outside of the cavity. In this example, a designer wants to use a CFS wall that has R-13+15.5. There are no entries in Table 6 with this exact combination of cavity insulation and CI. There are at least two ways the data in Table 6 can be used in this situation. It is important to note that the Table 6 assemblies do not include the impact of cladding. For a more exact U-factor, cladding can be added to the R-value in Table 6. For example, the R-13+15 assembly in the Example 1 has a U-factor with an overall assembly R-value of 19.8. One can thus add the value of any cladding to the assembly R-value. Assuming a siding system with an R-5 is selected, one can add this value to the R-19.8 to yield an assembly R-value of 24.8. Inverting this yields a U-factor of 0.40. A second option would be to add an additional R-5 of CI to the base wall. This might be the approach taken if the cladding selected has a negligible R-value. Alternately, any combination of cladding or CI that gives the same overall R-value can be selected.

Walls with Empty Cavities

Empty cavity walls represent a special case for CFS construction due to the placement of all of the insulation outside of the framing. As shown in Figure 3, the framing in these walls does not provide the type of thermal bridge through the insulation as is the case with cavity insulation.

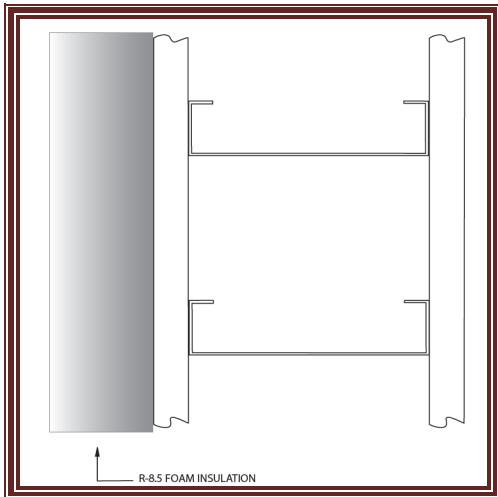


Figure 3. Wall with CI and no cavity Insulation

There are at least two methods available for U-factor determinations of empty cavity assemblies – hot box test results (see previous section) or the method used in ASHRAE Standard 90.1 Appendix Table A3.3.

For a closed cavity without cavity insulation, an R-value for the empty cavity is defined in ASHRAE Standard 90.1 Appendix Table A9.2B (2013 edition). This table credits the empty cavity with a maximum R-value of 0.79 or 0.91 for 16 and 24 inch spacing, respectively. Thus, the overall U-factor can be determined as follows:

Equation 3

$$U_w = 1/[R_s + R_e]$$

Where:

U_w = U-factor of wall

R_s = R-value of all elements in the path through the wall excluding the framing and the empty cavity (i.e., R-values of the gypsum board, inside and outside air films, sheathing, and exterior continuous insulation if present). See Appendix A for R-values of common construction materials.

R_e = R-value of the empty cavity from ASHRAE Standard 90.1 Table A9.2B (R-0.79 for 16 inch spacing and R-0.91 for 24 inch stud spacing or wider).

There is considerable controversy over the credit for an air gap such as in an empty cavity even within the ASHRAE Standard 90.1 envelope subcommittee charged with maintaining this section of the standard. Although additional depth of studs will increase

the R-value of the empty cavity, the standard currently only allows credit for a maximum air space of four inches (i.e., the R-0.91 is the maximum allowable credit).

Modified Zone Method

The modified zone method (MZM) was developed in 1995 by ORNL to address deficiencies with the conventional zone method when applied to thin steel sections such as used with CFS. It was based on tests of clear wall assemblies. A clear wall has no openings for doors or windows. Rather, it only consists of studs and top and bottom tracks.

Although the MZM in its current state of development is most applicable to clear wall assemblies, it can also be applied to a limited set of other wall types that are common in today's buildings. Some curtain wall assemblies have framing factors similar to a clear wall assembly. Likewise, it is not unusual to find walls with few or no openings on side and rear elevations. These tend to have framing factors that are close to those in a clear wall.

There is no consensus on the maximum framing factor permitted with the MZM method. SFA research has demonstrated that at framing factors in the 23% or higher range, the method should not be used. At the other end of the spectrum, small increases in the framing factor beyond a clear wall assembly will not significantly impact a steel framed wall's performance. For this reason, it is appropriate to use the MZM for clear walls, but the method will also provide reasonably accurate U-factors for walls with only a few openings. As indicated in Table 1, 16% is recommended as the high end of the range of framing factor for use of the MZM. This is just slightly higher than the 11% -14% in a typical clear wall assembly.

The MZM calculations are complex compared to the other methods in this guide. Detailed examples for MZM calculations can be found in the 1995 AISI Thermal Design Guide for Exterior Walls or in the ASHRAE Handbook of Fundamentals (Ref.1, 5). There have also been some online and other calculators developed for MZM calculations, but none have been updated to current insulation practices. A chart-based approach for the MZM developed for the 1995 AISI Guide is provided in Figure 4. This chart is believed to produce results within 2% of the results from the more complex calculation approach. It is not applicable for walls without continuous exterior insulation.

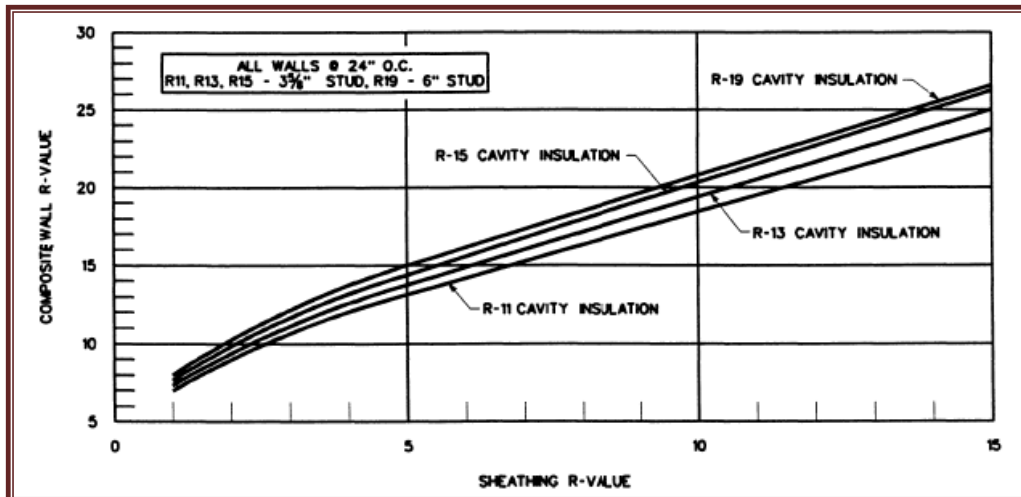


Figure 4. Chart to determine composite wall R-value based on MZM (Source: AISI Thermal Design Guide for Exterior Walls-1995).

To determine a U-factor from Figure 4, apply the following steps:

1. Find the R-value of the exterior insulation on the proposed wall design along the x axis of Figure 4. The chart was based on an assumption of an exterior wood-based sheathing under the continuous insulation. Thus, only use the R-value of the foam insulation for the starting point on the x axis.
2. Follow a straight line vertically upward to the intersection with the curve that represents the cavity insulation in the proposed design.
3. Follow a horizontal line over to the y axis intersection to determine the assembly or composite R-value of the wall.
4. Divide 1 by the R-value from Step 3 (i.e., determine the reciprocal) to determine the U-factor of the wall.

A line does not exist for R-21 insulation on Figure 4. In this case, use of the R-19 line will provide a slightly conservative but almost indistinguishable U-factor for the R-21 assembly. Note that as the cavity insulation R-value increases, there is little additional value gained. The bulk of the assembly's thermal resistance is in the CI as its thickness increases.

The chart method is an efficient tool to determine U-factors when the R-values of the cavity and CI are known at the start. For code compliance, the more likely scenario is one where the U-factor is known and the R-values of the cavity and CI need to be determined. This can be approached by first inverting the U-factor (divide 1 by the assembly maximum U-factor specified by the code) and following steps outlined previously but in reverse. Any combination of cavity and CI R-values should result in a U-factor less than or equal to the target U-factor.

Chapter 4 - Code Compliance Options and Examples

Chapter 1 of this guide identified multiple paths for code compliance. This chapter provides more detailed information on applying each of the methods, including examples where appropriate of the various prescriptive options. For the performance options that require computer simulations using specialized software, the discussion is limited to a qualitative discussion of available options and approaches that may result in more cost-effective designs than prescriptive designs.

Instructions for Using the Prescriptive Options in Codes

Prescriptive Option Based on R-values of Insulation

1. First, determine the appropriate climate zone based on the location of the building. Often times the local building code will identify the jurisdiction's climate zone. The climate zone map used in the IECC and ASHRAE Standard 90.1 is reproduced in Figure 2.
2. Select the minimum R-value(s) from the appropriate code or standard (Table 5.5.1 through 5.5.8 in ASHRAE Standard 90.1, Table C402.1.3 for commercial buildings or Table R402.1.2 for low-rise residential in the IECC). When a value in the code only requires cavity insulation, one number is shown such as R-13. Whenever continuous exterior insulation is required, a "+" sign followed by a second value is listed in the table, such as R-13 +5. The first value is for cavity insulation and the second is for continuous insulation .
3. Select cavity insulation and continuous insulation for the proposed design that meets or exceeds the required R-values.

Below are two examples from the IECC for a building in Richmond, Virginia.

Example 3. Office building. The IECC has two columns in Table C402.1.3. In this case, the column labeled "all other" applies because an office is a commercial building and not a residential building (the other choice in this table is the column marked "Group R" that applies to residential buildings other than low-rise such as a hotel or apartment). Richmond is in Climate Zone 4 as shown in Figure 2. From IECC Table C402.1.3, a CFS wall assembly in a commercial (all other) building in Climate Zone 4 has a corresponding prescriptive wall assembly of R 13 +7.5. The proposed wall must have at least these two levels of insulation to comply using the prescriptive R-value option.

Example 4. Single family home or townhouse under four stories in Richmond, VA. Table R402.1.2 of the residential part of the IECC lists requirements for these building types. However, steel framing is not represented in this table. Instead, the IECC residential provisions express the required R-value for a wood framed wall. In the Richmond location using Climate Zone 4, the IECC shows two options for a single family

home with wood walls – either R-20 or R-13+5. The code further requires that CFS walls conform to an equivalent R-value for the wood wall.

The equivalent R-values are provided in Table R402.2.6 of the IECC. There are many different combinations that are contained in the IECC to meet the equivalency requirement. However, the equivalency table is not comprehensive. It may require the use of the U-factor prescriptive option for design assemblies that are not shown in the pre-calculated table or for purposes of investigating a more cost-effective assembly. Some typical options for walls are shown in Table 7. Any design requiring more than R-15 cavity insulation must use 5.5” or 6” deep studs.

Based on Table 7 for R-20 wood walls, the Richmond home with CFS walls with a minimum of R-13+7.7 (R-13 cavity insulation and R-7.7 CI) insulation would comply with the code with studs at 24 inches on center. The CI would need to be increased to R-8.9 with studs at 16 inches on center.

Table 7. Examples of equivalent wood and CFS R-values from IECC (Source: 2015 IECC)

Wood frame R-value requirement	Cold Formed Steel Equivalent R-value
16 inch stud spacing	
R-13	R-13+4.2 or R-15+3.8 or R-0+9.3
R-20*	R-13 8.9 or R-19 + 7.8 or R-0+14
24 inch stud spacing	
R-13	R-13+3 or R-15+2.4 or R-0+9.3
R-20*	R-13+7.7 or R-19+6.3 or R-0+14

*Also applies to R-13 + 5 in a wood wall

Prescriptive Option Based on Assembly U-factors

Under this approach the designer must show how a wall assembly U-factor is equal to or lower than the code-required maximum U-factor. The following steps and examples demonstrate the approach

1. Identify the climate zone where the building is located, using the map in Figure 2 or by consulting your local code.
2. Select the U-factor required by the adopted code. U-factors from the 2015 IECC are in Table C402.1.4 for commercial buildings (including large residential buildings) and Table R402.1.4 for low-rise residential buildings. In ASHRAE Standard 90.1, Tables 5.5.1 to 5.5.8 apply.
3. The proposed design U-factor must be equal to or less than the maximum U-factor in the adopted code. Test data or U-factors from this report are appropriate sources of data. Be certain that the building official approves the use of the data and calculation method before proceeding with design or construction.

Example 5: Hotel in Richmond, Virginia with nominal 3.5" wall cavity. Richmond is located in Climate Zone 4 (See Figure 2). For a steel framed wall, the IECC requires a maximum U-factor in Table C402.1.4 of 0.064 under the column labeled "Group R." This is the same requirement in Table 5.5.4 of ASHRAE Standard 90.1. From Table 1 in Chapter 2 of this guide, a wall assembly with studs at 16 inches on center will meet this requirement when the cavity insulation is at least R-13 and the CI is at least R-7.5 (otherwise designated as R-13+7.5).

Example 6: Single family home in Richmond, Virginia with 3-5/8" wall studs at 24 inches on center.

In this example, the same Climate Zone 4 is applicable. Table R402.1.4 from the IECC must be used. Unlike the R-value prescriptive method in the IECC, there is no separate table requiring equivalence to wood - just a single U-factor applicable to all framed walls. In this case the U-factor is 0.60. From Table 1 in Chapter 2 of this guide, a wall with R-13+7.5 insulation would comply. Notice that this is slightly less than the R-13+7.7 required by the R-value path in Example 4. This demonstrates the importance of evaluating the different paths to obtain the most economical design.

Performance Compliance

Since the mid-1990s, the use of software packages for energy simulations of homes and commercial buildings, although not routine, has grown considerably. Simulation tools over time have become very affordable. There are even a few programs that are free, but more sophisticated programs that conduct specific code evaluations can cost from several hundred to thousands of dollars.

What is the advantage of running a computer simulation to determine energy performance or for code compliance? Generically speaking, performance simulations tend to provide a more efficient design in terms of balancing costs and energy savings. For example, the prescriptive requirements in ASHRAE Standard 90.1 were developed to a large extent by optimizing each component. However, that approach does not always place available resources in the most cost-effective part of the building. The money spent to minimize heat loss through walls may be a good idea in a cold climate but those dollars may be better spent on shading or windows with a lower solar heat gain coefficient in a hot climate. Similarly, it may be more cost-effective to invest in lighting or better equipment efficiency in some building types versus the envelope. The performance option allows the builder or designer more flexibility in determining where to invest their energy efficiency dollars.

In all building types, the most significant competitive disadvantage for CFS is the need for continuous insulation (CI) on exterior walls. In cases where wood walls also are required to have CI, the thickness of the CI is almost always higher for CFS walls. This situation exists in the IECC and ASHRAE Standard 90.1.

The competitive disadvantage related to CI is often good enough reason to consider a performance simulation to trade off some of the cost of CI for more efficiency elsewhere in a building. However, there are other factors that make performance simulations an appealing option including:

1. Foam insulation complicates the fastening of claddings as the CI becomes thicker. Although a ½" or 1" foam insulation layer is not usually problematic, thicker layers require more expensive fasteners, require more labor hours to install, and may require a special engineered design for those fasteners to hold heavier claddings.
2. Thick layers of CI require special detailing at corners for attachment of claddings.
3. CI results in a wider wall, sometimes reducing the useable space of the building and requiring jamb extensions or other special detailing at window and door openings.
4. The International Building Code and most other building codes require special fire tests for assemblies with foam plastic (including insulation) on the exterior of a wall to prevent fire propagation to higher floor levels.

The above is not meant to imply that use of CI is always to be avoided, but rather that there are often more cost-effective ways to design with CFS assemblies. In some cases, CI may be the best choice. For example, when a stucco exterior is desired, a wall system that relies completely on exterior CI may be the most cost-effective option.

In single family homes and similar low-rise residential buildings, ghosting is another good reason to use CI in climates with a long heating season. Ghosting is a temperature-driven phenomenon where dust and other particles accumulate on the interior surface of walls or ceilings at locations where the framing is located within the assembly. Often the source of the particles is related to excessive candle burning or other unusual activities in homes. Ghosting is rare and in many cases takes years for it to appear visible to the naked eye. However, some cases of visible ghosting have been observed in as few as six months.

Climate Zones 1 and 2 represent the southern-most areas of the United States. In these climates, the risk of ghosting is negligible due to the low temperature difference across the envelope. It is also likely that ghosting is not of concern in most of Climate Zone 3. However, more research is needed to definitively identify ghosting criteria in moderate climates before the industry could recommend going without at least R-3 continuous insulation for homes except in Climate Zones 1 and 2. In commercial buildings and other occupancies that undergo frequent cleaning or re-painting due to occupancy changes, ghosting may never appear, even in colder climates. Documented cases of ghosting with both wood and steel framing have been almost entirely limited to single family homes and other low-rise residential buildings.

After considering ghosting issues, a builder or designer can eliminate or reduce continuous exterior insulation by improving other components of the building through the use of performance path compliance. For example, a builder may decide to use better windows, modify the stud spacing, or use more-efficient HVAC or water heating equipment to improve energy performance.

To make the performance option effective in trading off CI for other efficiencies, a designer needs to know which building systems to concentrate on in their simulations.

Otherwise, one could spend a significant amount of time looking at simulations that might otherwise yield no practical construction or cost advantages. Table 8 shows some options that can be examined to reduce or eliminate the need for CI. Table 8 is designed for guidance only. Every building is different and needs its own simulations to confirm the building is complying with the code in its specific climate zone.

Table 8. Candidate trade-off options for CI in CFS buildings.

Options with energy savings above the prescriptive code minimum	Comments
Increase the R-value of attic insulation	Attic insulation is much less expensive than continuous insulation on walls. It also is practicable in that there is typically no need to make other building modifications to add more insulation in the attic.
Increase the R-value of insulation in low-slope roofs.	This typically amounts to using more CI on the roof and decreasing it on the walls. However, adding CI to the roof is much less complex than walls due to the presence of door and window openings and cladding attachment issues with walls.
Reduce the air leakage of the building to below the maximum allowed in the code.	This requires confirmatory tests of the air leakage rate which is complex for larger buildings.
Reduce the solar heat gain through buildings by decreasing the SHGC (solar heat gain coefficient) of windows or using projections to shade openings.	This is generally more effective in warmer climates.
Reduce the U-factor of windows	If the SGHC is reduced as indicated above, the U-factor typically also goes down with a specific window.
Increase the efficiency rating of heating or cooling equipment.	This is one of the more efficient trade-offs, especially in cooling-dominated climates. It is permitted in ASHRAE Standard 90.1 and the commercial part of the IECC but not in the residential part.
Increase the efficiency of water heating equipment.	Effective in single family and other residential occupancies with individual water heaters in each unit. It is permitted in ASHRAE Standard 90.1 and the commercial part of the IECC but not in the residential part.

The requirements for performance simulations are contained in Section C407 of the IECC for commercial buildings and Section R405 for homes. ASHRAE Standard 90.1 offers two performance options. Chapter 11 of the standard addresses only those loads that are regulated in the prescriptive requirements and is called the energy cost budget

method. Appendix G of the standard is a more comprehensive approach that is also suitable for use in energy rating programs.

In all cases, the performance option has some similarities in how it is implemented. Basically, the proposed building is described in the simulation model in terms of components and their efficiencies. The IECC and ASHRAE Standard 90.1 describe a standard reference design that is based for the most part on the prescriptive requirements. The same building is also simulated in its proposed state (with some limitations for some components as described in the code or standard). The energy cost or use for the proposed building must be no more than the standard reference building. The software package for code compliance must generate the standard reference building automatically.

Simulation Tools

Neither the author, the Steel Framing Alliance, AISI nor any of our affiliates endorse a specific software package for simulations. However, in order to use the performance option, some information is necessary to understand what programs are available. Always check with your governing code authority on a specific program before applying it to a proposed design.

The use of the performance option requires simulations to be run with “approved” software. The term “approved” is used loosely because although there are a number of organizations that certify, review, or otherwise assess software, the determination of what is acceptable rests with the local building department. Building officials and designers most often look to the U.S. Department of Energy (DoE), Energy Star, RESNET (Residential Energy Services Network- a nationally-recognized organization of home energy raters), or state code requirements for guidance on software tools to approve.

On one hand, it is encouraging that the software industry is healthy and competitive as evidenced by hundreds of software tools listed in DoE’s directory of simulation tools (http://www.eere.energy.gov/buildings/tools_directory/). On the other hand, the sheer number of options can be intimidating. Fortunately, a group of simulation tools has risen to the top as the most widely-used and recognized in the United States. Some of the more-widely used programs include:

1. COMCheck, a free download for simplified commercial code compliance from the U.S. Department of Energy (DoE)
2. RESCheck, a free download for simplified residential code compliance from the U.S. DoE;
3. Energy Plus, available from DoE. Some private software companies offer a user-friendly front end for ease of use. This is more of a full simulation program versus COMCheck.
4. Energy Gauge, available from the Florida Solar Energy Center. A version is available for commercial or residential buildings. Offers a variety of simulation and code compliance options.
5. REMDesign, available from Architectural Energy Corp. This is strictly for low-rise residential buildings. Offers a variety of code check and simulation options versus RESCheck.

Some programs are available for free while others cost hundreds of dollars for a simple license or into the thousands of dollars for more sophisticated packages. Costs can be higher or lower depending on how many licenses are required and features desired. Information on these and other software packages can be found at the DOE website.

In general, there is a lack of consistency related to how each of the software programs calculates the thermal resistance or conductance (R-value or U-factor) of CFS members and assemblies. If a user selects the default values or library files for CFS framing, they may end up with a less than accurate building model, particularly in colder climates. Some simulation programs come with libraries of all the required information for framing assemblies but some also require or permit the user to input these thermal characteristics. A proficient user can adjust the U-factors for a component to achieve accurate results. The U-factors in Chapters 2 and 3 are recommended for use in simulations except in cases where the code or standard dictates otherwise.

Note that California has its own requirements and approved software that comply with California's Title 24 energy provisions (Ref. 9). Always confirm your assumptions and software tool with the appropriate building code department.

General Information for Using the Simulated Performance Approach

Providing detailed information on how to run simulations is beyond the scope of this Guide. Some programs are intuitive and a user with some basic understanding of energy codes and technologies can be self-taught to run fairly simple buildings. More likely, some special training will be necessary. With a moderate amount of building knowledge, most of the packages will require a few days to become proficient enough to run relatively conventional buildings. More sophisticated designs with innovative heating and air-conditioning equipment will require longer learning times. Once some level of comfort or proficiency is developed, the general approach for running simulations with the intent of looking for economical solutions is as follows:

1. Assemble completed floor plans, wall sections, and specifications for the proposed building. If specifications for the energy systems are not yet determined, run the initial simulation using minimum prescriptive code requirements for insulation R-value and equipment efficiency. Some simulation tools do this automatically. Most tools provide menus to select your climate zone.
2. If the selected software is approved by your governing code authority for use as a compliance tool, then it is appropriate to use the default U-factors built into the software or in its library. However, you may create a more accurate model by importing your own U-factors based on Table 1 in Chapter 2 of this guide or calculated using the methods discussed in Chapter 3.
3. Run additional simulations by changing items that can improve the building's performance. Some programs do whole-building evaluations as well as a Total UA alternative, which allows a user to specify less insulation in one part of the building if it is made up elsewhere

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8. *Thermal Impact of Fasteners in High-performance Wood-Framed Walls*, Dale Christensen, Presented at the December 2010 International Conference, Thermal Performance of Exterior Envelopes of Whole Buildings XI. Clearwater Beach, FL.
9. *2013 Building Energy Efficiency Standards*, Title 24, Part 6, California Energy Commission, May 2012, (www.energy.ca.gov/title24/2013standards/index.html).

Appendix

R-value of common construction materials used in CFS wall assemblies

Source: ASHRAE Standard 90.1-2013 Appendix A.

Material	R-value
½ inch gypsum board	0.45
5/8 inch gypsum board	0.56
¾ inch stucco	0.08
Solid wood (per inch)	1.25
Interior air film	0.68
Exterior air film	0.17

R-values of continuous insulation and cavity insulation vary by manufacturer, product type, density and thickness. For walls, cavity insulation is typically available in R-11, R-13, and R-15 for nominal four inch walls and R-19 or R-21 for nominal 6 inch walls. Use the listed R-value provided on or with each product.

Continuous semi-rigid foam insulation is generally available in 1/2 inch or wider thicknesses for walls. Most products are available in ½ inch increments but the R-value varies by manufacturer and other variables. The same thickness for the same basic product does not always equal the same R-value. As with cavity insulation, use the R-value provided on or with each product