research report

The Challenge of Calculating U-factors for Cold-Formed Steel C-shape Wall Assemblies using Framing Factors

RESEARCH REPORT RP20-3

April 2020

American Iron and Steel Institute

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The Challenge of Calculating U-factors for Cold-Formed Steel C-shape Wall Assemblies using Framing Factors

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April 16, 2020

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EXECUTIVE SUMMARY

The American Iron and Steel Institute (AISI) goal is to develop an ANSI approved standard that can be used to calculate the U-factors for cold-formed steel C-shape clear wall assemblies that would be acceptable for energy code analysis and compliance. The objective of this project was to determine whether the framing factor for cold-formed steel C-shape frame walls was an acceptable metric to account for the thermal impact on U-factors due to the additional studs, tracks, plates, headers and sills beyond those of clear walls.

The scope of this project was limited to cold-formed steel C-shape framed walls with framing factors that account for the additional studs, tracks, plates, headers and sills beyond those of clear walls.

The technical approach was to use framing factors as the metric to fully account for the additional framing typically encountered in the construction of actual cold-formed steel C-shape framed walls. The results of the previous AISI project developed U-factors for clear wall assemblies with on center spacings of 6, 12, 16 and 24 inches which equate to framing factors of 0.25, 0.125, 0.094 and 0.063. This is significant because it extended the range of framing factors up to 0.25 for the first time which would include the typical values of 0.22 to 0.24 that are found in energy codes to use for setting the criteria for wood framed walls.

Determination of the framing factor for steel framed walls (FF_{OTZ}) is complex due to the two dimensional characteristics of the thermal anomaly (OTZ). It is further complicated when there are additional studs, tracks, plates, headers and sills. Adjoining studs and intersections create complexities that were not directly modeled. The approach was to determine whether the framing factor procedure would account for these complexities. The analysis clarified that this approach was not acceptable.

Another approach was to determine whether there was any relationship between the clear wall framing factors and the CHB test data. The concept was that the clear walls had framing factors ranging from 0.063 to 0.25 which encompass the 0.23 from the test walls. The 0.23 framing factor from the test walls would be equivalent to a clear wall on center spacing of 7 inches. Although a correlation was developed for this one configuration there is currently insufficient data to propose it as the general solution.

The use of framing factors is not an acceptable metric to account for the thermal impact on U-factors for cold-formed steel C-shape framed walls with additional studs, tracks, plates, headers and sills beyond those of clear walls. A framing factor does not adequately account for the complexities and interactions due to the thermal anomalies associated the steel framing.

The thermal performance of 24 in. on center steel framed wall constructions with a framing factor of 0.23 has been shown to correlate with the U-factors for a 12 in. on center clear wall which has a framing factor of 0.125. Clearly there are complex interactions associated with the cavity and sheathing insulations combinations which impact the overall thermal performance even though the structural framing does not change.

In order to fully develop a U-factor calculation procedure to account for the complexities of framing due to additional studs, tracks, plates, headers and sills further research is required. The research would require extensive additional CHB tests or sophisticated computer modeling to quantify the thermal complexities due to adjoining and intersecting studs beyond those of clear walls.

The project monitoring committee (PMC) for this study, formed by AISI, consisted of the following members:

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1 - INTRODUCTION

The American Iron and Steel Institute (AISI) was in the process of completing a project to develop an ANSI approved standard that can be used to calculate the U-factors for cold-formed steel C-shape clear wall assemblies. The objective of this project was to use those results and expand the procedure to calculate U-factors for actual cold-formed steel C-shape wall assemblies, similar to that done for wood framed walls, by accounting for the additional framing members including studs, tracks, plates, headers and sills.

2 - BACKGROUND

A key feature in the development of U-factors for wall assemblies in energy codes is the use of framing factors to account for studs, plates, headers and sills in wood framed walls. Research had been completed on wood framed constructions to determine typical framing factors (ASHRAE 2001) which are used when developing energy code criteria. Typical framing factors for wood frame construction are 0.25 for 16 in. on center spacing and 0.22 for 24 in. on center spacing (ASHRAE 2019). However, currently there is no accounting for similar features in cold-formed steel C-shape wall assemblies since the U-factors used to specific the energy code criteria are based on clear wall assemblies (ASHRAE 2019, International Energy Conservation Code (IECC-2018).

The underlying principle behind the application of framing factors for wood framed construction is that the parallel path U-factor calculation procedure correctly applies to all of the construction. However, this basic principle does not equally apply to cold-formed steel C-shape wall assemblies due to the geometry of the C-shape, the thickness of the steel and the on center spacings of the studs. Modeling of steel C-shape has led to the creation of thermal areas which increase the width of the framing member beyond the actual dimension. The modified zone method defines this dimension as the zone of thermal anomalies (W) (ASHRAE 2017) while AISI has a similar definition which is the overall thermal zone (OTZ)
. The OTZ dimensions for steel constructions vary depending upon the R-values of the cavity insulation, the exterior foam sheathing, the thickness of the steel and the on center spacing of the framing members.

Recognizing that the information concerning the thermal performance of steel C-shape clear wall assemblies was limited AISI conducted research to expand the data to include three additional steel thicknesses, on center spacings of 6 and 12 inches plus nominal stud dimension 2x8, 2x10 and 2x12 C-shapes (McBride 2020). By analyzing the additional data it would lead to the ability for framing factors to account for additional framing members including studs, tracks, plates, headers and sills that are typical of actual wall constructions. However, it may not be that simple since the configuration of the additional steel C-shapes influence the overall U-factor (Kosny 2007).

3 - SCOPE

The scope of this project was limited to cold-formed steel C-shape framed walls with framing factors that account for the additional studs, tracks, plates, headers and sills beyond those of clear walls.

4 - DEFINITIONS, ABBREVIATIONS and ACRONYMS

4.1 - General

Selected terms unique to this report are defined in this section.

4.2 - Definitions

C-Shape: A cold-formed steel shape used for structural members and nonstructural members consisting of a web, two flanges and two lips.

Clear Wall: A wall area containing only insulation and necessary studs with no windows, doors, corners, tracks or other connections with envelope elements.

Clear Wall Stud Spacing: The dimension of the clear wall on center stud spacing.

Designation Thickness: The minimum base steel thickness expressed in mils and rounded to a whole number.

Framing Factor: The fraction of the total area that is framing.

Framing Factor, C-shape (FF_{cs}): The thickness of cold-formed framing member divided by the width of the flange.

Framing Factor, OTZ (FF_{OTZ}): The Overall Thermal Zone (OTZ) divided by the on-center spacing of the framing member.

Overall Thermal Zone (OTZ): The resultant effective area based on an analysis procedure that is designed to account for the thermal impact of cold-formed steel framing members in the resultant overall U-factor of the wall assembly.

Track: A structural member or nonstructural member consisting of only a web and two flanges.

4.3 - Abbreviations and Acronyms

AISI	- American Iron and Steel Institute
ANSI	- American National Standards Institute
ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	- British thermal unit
Btu/h-ft^2-^{o}F	- British thermal unit per hour per square foot per degree Fahrenheit
CHB	- Calibrated Hot Box

ft	- foot
in.	- inch
oc	- On Center – (inches)
OTZ	- Overall Thermal Zone – (inches)
R-value	- Thermal Resistance – (h-ft^2-^{o}F/Btu)
Rcav	- Thermal Resistance of the Cavity Path - (h-ft^2-^{o}F/Btu)
Rshe	- Thermal Resistance of the Rigid Foam Board Sheathing - (h-ft^2-^{o}F/Btu)
Rweb	- Thermal Resistance of the Web Path - (h-ft^2-^{o}F/Btu)
Stud	- Nominal Size of the Cold-Formed Steel C-channel – (inches)
U-factor	- Thermal Transmittance - (Btu/h-ft^2-^{o}F)

5 - TECHNICAL OBJECTIVE

The objective was to determine whether the framing factor for cold-formed steel C-shape steel walls was an acceptable metric to account for the thermal impact on U-factors due to the additional studs, tracks, plates, headers and sills beyond those of clear walls.

6 - TECHNICAL APPROACH

The technical approach was to use framing factors as the metric to fully account for the additional framing typically encountered in the construction of actual cold-formed steel C-shape framed walls. The results of the previous AISI project developed U-factors for clear wall assemblies with on center spacings of 6, 12, 16 and 24 inches which equate to framing factors of 0.25, 0.125, 0.094 and 0.063, (McBride 2020). This is significant because it extended the range of framing factors up to 0.25 for the first time which would include the typical values of 0.22 to 0.24 that are found in energy codes to use for setting the criteria for wood framed walls.

In terms of the definition of a framing factor, the width of the highly conductive path is critical. For wood framed walls this is the width of all the framing members, see Fig. 6.1. However, for steel C-shape framed walls the width would be characterized by the thermal anomaly due to the highly conductive steel. The flanges create a two-dimensional thermal impact which was accounted for in the determination of the thermal zone due to the steel framing. This was defined as the Overall Thermal Zone (OTZ), see Fig. 6.2. The dimension of the OTZ depends upon the thermal resistances of the cavity insulation, the rigid foam board sheathing and the on center spacings.

Fig. 6.1 - Typical Wood Framed Wall

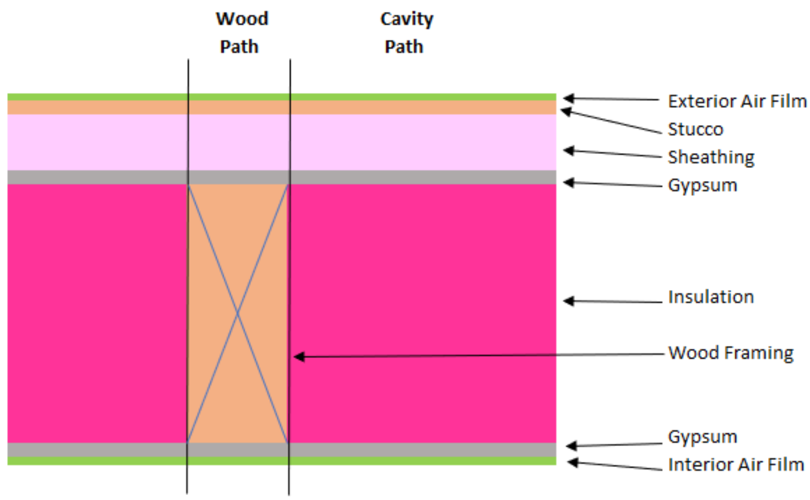
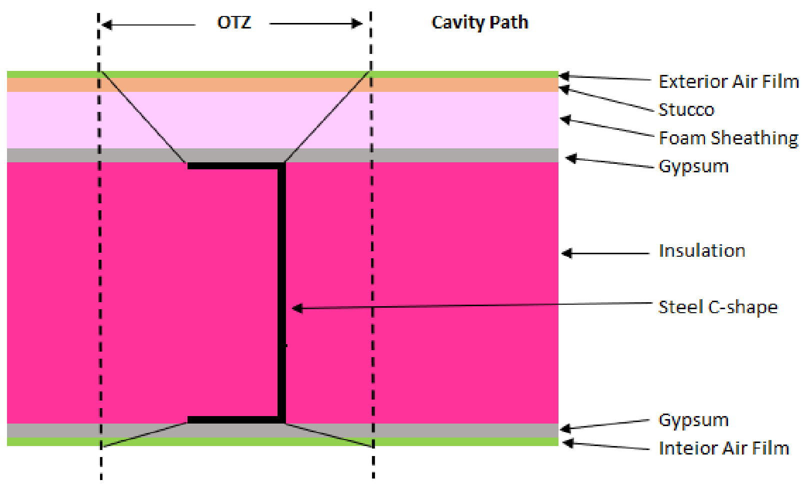


Fig. 6.2 - Overall Thermal Zone (OTZ) in Steel C-shape Wall



The fundamental equation to calculate a U-factor is presented in Eq. 6.1.

$$U = (1 – FF)/R_{cav} + FF/R_{frame} \qquad 6.1$$

Where:

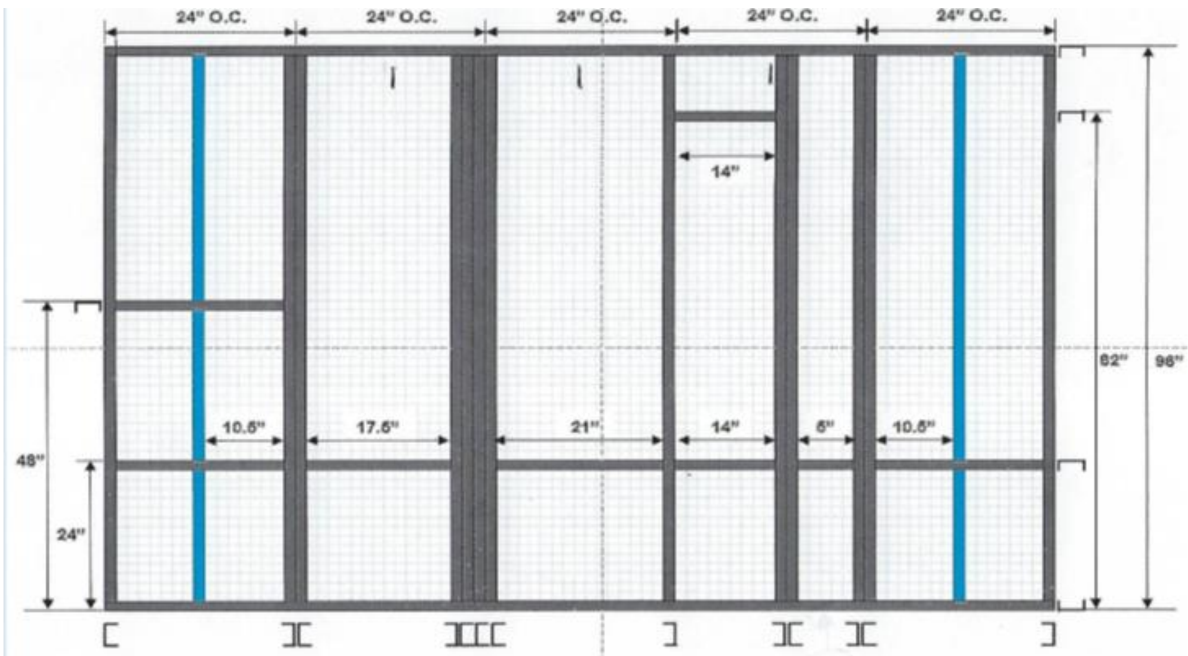
U	= Thermal Transmittance, Btu/hr-ft^2-^{o}F
FF	= Framing Factor, dimensionless
R_{cav}	= Thermal Resistance of the Cavity Path, hr-ft^2-^{o}F/Btu
R_{frame}	= Thermal Resistance of the Frame – Wood or OTZ, hr-ft^2-^{o}F/Btu

Determination of the framing factor for steel framed walls (FF_{OTZ}) is complex due to the two dimensional characteristics of the thermal anomaly (OTZ). It is further complicated when there are additional studs, tracks, plates, headers and sills. Adjoining studs and intersections create complexities that were not directly modeled. The approach was to determine whether the framing factor procedure would account for these complexities.

7 - RESULTS

The technical basis for the analysis used the results from calibrated hot box tests for 21 walls constructed using 2x4 and 2x6 steel studs spaced 24-inches on center with various combinations of cavity and exterior sheathing insulations (Desjarlais 2011, Desjarlais 2012). Additional steel studs were added to be representative of the framing typically encountered for the studs, tracks, plates, headers and sills in order to achieve a total framing factor of 23%, see Fig. 6-3.

Fig. 6.3 - Test Wall Framing Details



A significant benefit of the research project was that the thermal properties of the key insulation materials were measured and reported as test values rather than assuming that the label properties were correct., see Table 6.1.

Table 6.1 - Calibrated Hot Box Test Results

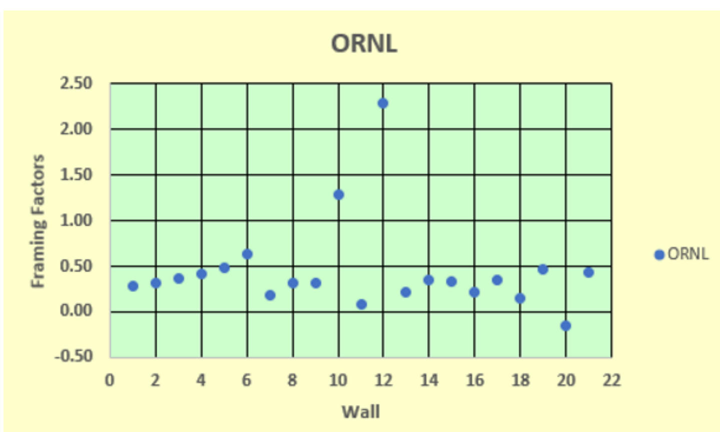
Wall	Studs - Mils	Test R-cav	Test Rshe	CHB Test R-value	CHB Test U-factor
1	2x4-43	12.8	3.8	10.8	0.093
2	2x4-43	12.8	5	12.1	0.083
3	2x4-43	12.8	7.4	14.2	0.070
4	2x4-43	12.8	9.6	16.1	0.062
5	2x4-43	12.8	12.1	18.1	0.055
6	2x4-43	12.8	15.3	20.1	0.050
7	2x4-43	13.5	0.5	7.3	0.137
8	2x4-43	13.5	3.8	10.4	0.096
9	2x4-43	13.5	5	12.2	0.082
10	2x4-43	0	8.3	9.8	0.102
11	2x4-43	0	9.6	11.9	0.084
12	2x4-43	0	12.1	13	0.077
13	2x6-43	16.3	0.5	7.2	0.139
14	2x6-43	16.3	3.8	10.7	0.093
15	2x6-43	16.3	5	12.5	0.080
16	2x6-43	20.4	0.5	7.4	0.135
17	2x6-43	20.4	3.8	11.1	0.090
18	2x4-43	0	8.4	11.4	0.088
19	2x4-43	0	13.9	16.7	0.060
20	2x6-43	0	8.4	11.6	0.086
21	2x6-43	0	13.9	16.7	0.060

The test wall studs were 0.047 in. steel and spaced 24-in. on center. The interior finish was ½" thick regular gypsum for all of the walls. The exterior finish was insulated sheathing except for walls 7, 13 and 16 which had ½" OSB while walls 18-21 had 5/8" exterior gypsum sheathing and EIFS finish applied except for wall 20. The U-factors were used to calculate framing factors for each of the walls. The fundamental U-factor calculation equation is Eq. 6.1 which can be solved for the framing factor as shown in Eq. 6.2.

$$FF = (U \times Rcav \times Rweb – Rweb)/(Rcav – Rweb) \qquad 6.2$$

The results are presented in Fig. 6.4.

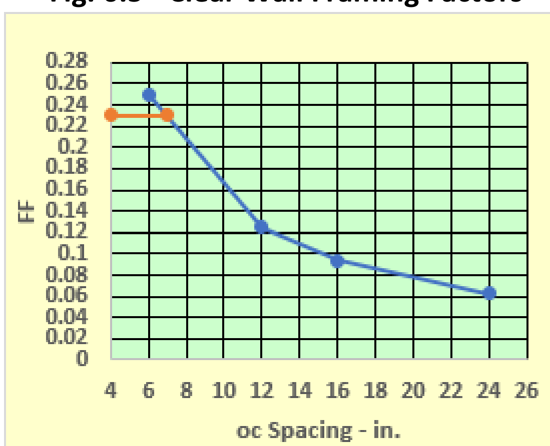
Fig. 6.4 - Calculated Framing Factors for Test Walls



The expectation was that using Eq. 6.2 and the CHB test data would establish a relationship between the experimental CHB test results and the traditional 0.23 framing factor. The original idea was that a simple offset would occur because the framing remained constant for each of the cases. The scatter exhibited in Fig. 6.4 was not expected. Clearly there are some complex interactions associated with the cavity and sheathing insulations which impact the overall thermal performance even though the structural framing does not change.

Another approach was to determine whether there was any relationship between the clear wall framing factors and the CHB test data. The concept was that the clear walls had framing factors ranging from 0.063 to 0.25 which encompass the 0.23 from the test walls, see Fig. 6.5. The blue line represents the framing factors for clear walls while the orange line represents the framing factor for the 21 CHB test walls. The 0.23 framing factor from the test walls would be equivalent to a clear wall on center spacing of 7 inches which is shown in Fig. 6-5.

Fig. 6.5 - Clear Wall Framing Factors



In order to understand how the CHB test results compare to the clear walls the U-factors for the test walls were calculated for the four on center spacings. The results are shown in Fig. 6-6 through Fig. 6-9.

Fig. 6.6 - Calculated U-factors for 6oc Clear Walls

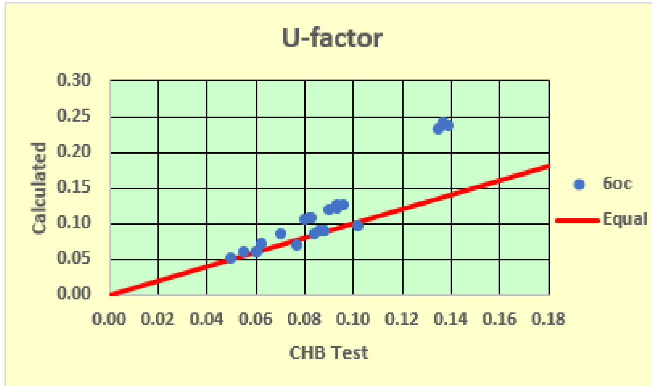


Fig. 6.7 - Calculated U-factors for 12oc Clear Walls

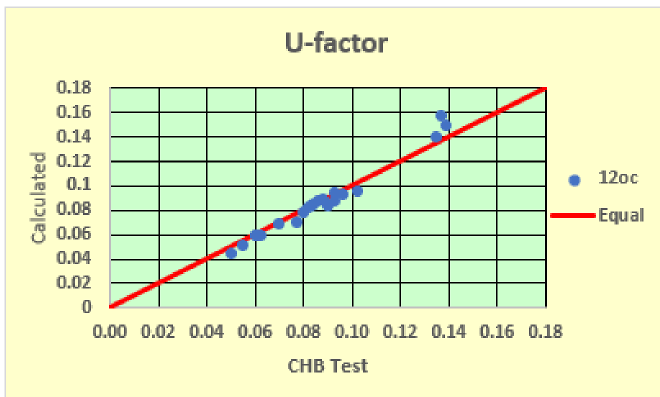


Fig. 6.8 - Calculated U-factors for 16oc Clear Walls

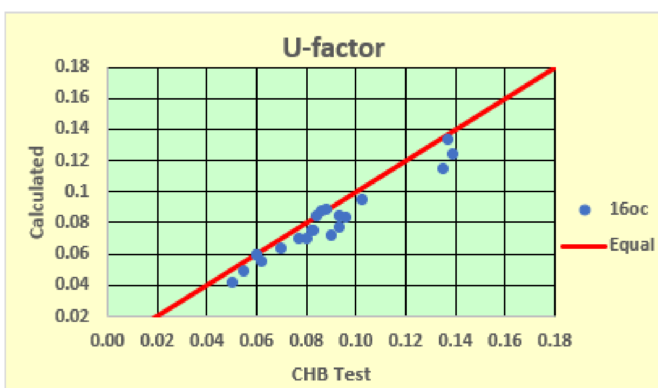
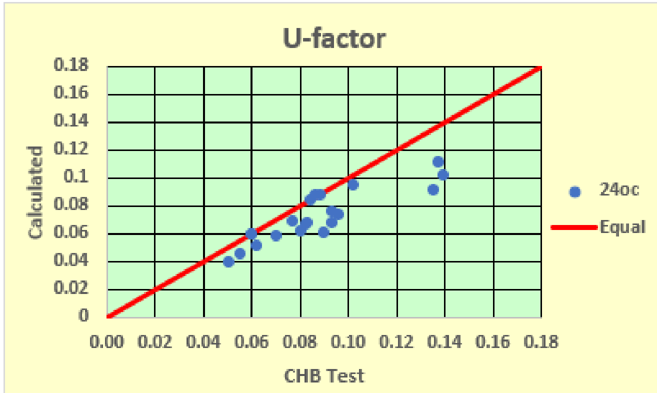


Fig. 6.9 - Calculated U-factors for 24oc Clear Walls



Since the framing factor of 0.23 results in an on center spacing of 7 inches the calculated U-factors that use an on center spacing of 6 inches would be relatively close to those measured in the CHB tests. However, there was a better correlation between the measured CHB U-factors and the 12 in. on center clear wall calculated U-factors. The average U-factor difference is -0.9% with a standard deviation of 5.8, see Table 6.2. Although a good correlation was identified it does mean that it would be universally applicable since different steel wall framing configurations may result in better correlations with different clear wall calculations.

Table 6.2 - Calculated U-factors for 12 oc Clear Walls

Wall	Studs - Mils	Test R-cav	Test Rshe	CHB Test R-value	CHB Test U-factor	12 oc Calc. U-factor	Calc. ΔU - %
1	2x4-43	12.8	3.8	10.8	0.093	0.0947	1.8
2	2x4-43	12.8	5	12.1	0.083	0.0837	0.8
3	2x4-43	12.8	7.4	14.2	0.070	0.0691	-1.3
4	2x4-43	12.8	9.6	16.1	0.062	0.0598	-3.5
5	2x4-43	12.8	12.1	18.1	0.055	0.0521	-5.3
6	2x4-43	12.8	15.3	20.1	0.050	0.0446	-10.8
7	2x4-43	13.5	0.5	7.3	0.137	0.1578	15.2
8	2x4-43	13.5	3.8	10.4	0.096	0.0936	-2.5
9	2x4-43	13.5	5	12.2	0.082	0.083	1.2
10	2x4-43	0	8.3	9.8	0.102	0.0954	-6.5
11	2x4-43	0	9.6	11.9	0.084	0.0851	1.3
12	2x4-43	0	12.1	13	0.077	0.0700	-9.1
13	2x6-43	16.3	0.5	7.2	0.139	0.1492	7.3
14	2x6-43	16.3	3.8	10.7	0.093	0.0879	-5.5
15	2x6-43	16.3	5	12.5	0.080	0.0785	-1.9
16	2x6-43	20.4	0.5	7.4	0.135	0.1409	4.4
17	2x6-43	20.4	3.8	11.1	0.090	0.0833	-7.4
18	2x4-43	0	8.4	11.4	0.088	0.0889	1.0
19	2x4-43	0	13.9	16.7	0.060	0.0597	-0.5
20	2x6-43	0	8.4	11.6	0.086	0.0883	2.7
21	2x6-43	0	13.9	16.7	0.060	0.0597	-0.5
						Avg. =	**-0.9**
						Std. Dev. =	**5.8**

8 - DISCUSSION OF RESULTS

The technical analysis and results have been presented in detail. A thorough analysis has been completed on the 21 CHB test wall results and shows that the framing factor was not an acceptable metric to account for the thermal impact of additional studs, tracks, plates, headers and sills in cold-formed steel C-shape framed walls beyond those of clear walls. However, a correlation was developed for the U-factors from the 21 CHB tests with the 12 on center spacing for the clear walls. This correlation was not expected nor could it have been predicted.

9 - CONCLUSIONS

The use of framing factors is not an acceptable metric to account for the thermal impact on U-factors for cold-formed steel C-shape framed walls with additional studs, tracks, plates, headers and sills beyond those of clear walls. A framing factor does not adequately account for the complexities and interactions due to the thermal anomalies associated the steel framing.

The thermal performance of 24 in. on center steel framed wall constructions with a framing factor of 0.23 has been shown to correlate with the U-factors for a 12 in. on center clear wall which has a framing factor of 0.125. Clearly there are complex interactions associated with the cavity and sheathing insulations combinations which impact the overall thermal performance even though the structural framing does not change.

10 - RECOMMENDATIONS

In order to fully develop a U-factor calculation procedure to account for the complexities of framing due to additional studs, tracks, plates, headers and sills further research is required. The research would require extensive additional CHB tests or sophisticated computer modeling to quantify the thermal complexities due to adjoining and intersecting studs beyond those of clear walls.

11 - REFERENCES

ASHRAE. 2001. Characterization of Framing Factors for New Low-Rise Residential Building Envelopes. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2020. Handbook of Fundamentals. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2019. Energy Standard for buildings except low-rise residential buildings. ANSI/ASHRAE/IES Standard 90.1-2019. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Desjarlais, A., K. Biswas, P. Childs, and J. Archley. 2011. Steady-State Thermal Performance Evaluation of Seventeen Steel-Framed Wall Assemblies. Oak Ridge: Oak Ridge National Laboratory.

Desjarlais, A., K. Biswas, P. Childs, and J. Archley. 2012. Steady-State Thermal Performance Evaluation of Four Steel-Framed Wall Assemblies. Oak Ridge: Oak Ridge National Laboratory.

Kosny, J., D. Yarbrough, P. Childs and S. Mohiuddin. 2007. How the Same Wall Can Have Several Different R-values: Relations Between Amount of Framing and Overall Thermal Performance in Wood and Steel-Framed Walls. Clear Water: DOE, ASHRAE, ORNL Conference – Thermal Envelopes X.

McBride, M. 2020. Development of a U-factor Calculation Procedure for Cold-Formed Steel C-shape Clear Wall Assemblies. West Hartford: American Iron and Steel Institute.

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