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

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ABSTRACT

Is it possible that the same wall material configuration can be described in different documents or publications with several different R-values? Is it possible that the same code R-value requirement can be satisfied by wall configurations of significantly different thermal performance characteristics?

The answers to both questions is yes, it is very likely.

What is even more surprising, in most cases of wood or steel-framed constructions, these confusing answers have very simple sources: the amount of framing considered for R-value analysis and the type of wall cavity insulation.

This paper documents, experimental and numerical analysis of thermal effects of various configurations of structural components in wood and steel-framed walls. In addition, consequences of installation imperfections in cavity insulation on thermal performance are analyzed. The main purpose of this work is to incorporate these findings into whole- building energy calculations and initiate discussion of changes in existing code requirements for the thermal performance of walls.

INTRODUCTION

During the last two decades the Oak Ridge National Laboratory (ORNL) Buildings Technology Center (BTC) has tested and evaluated hundreds of building envelope technologies using a hot-box apparatus. This collection of technical information, thermal performance data, and a very unique experience in thermal analysis, combined with the fact that ORNL is a government research facility that is not associated with commercial interests, enables an objective evaluation of the existing code requirements, thermal calculation methods, and performance ratings.

R-values or U-values have been used for decades as measures of thermal performance of building envelope components. However, there have always been numerous disagreements regarding thermal calculation methods, definitions used by code documents, or required representative configurations. This paper is trying to point out some potential incongruities. This work deals with wood and steel-framed wall technologies. In both cases, framing members represent significant thermal bridges compromising nominal thermal performance of the cavity insulation. That is why it is so important to correctly evaluate the amount of framing and its thermal impact on the surrounding area. Framing factor expressed as a% of the total wall area represented by the framing members is widely used today in experimental and theoretical analysis. Traditionally, in hot-box testing of wood-framed walls, the framing factor has been between 10 to 14%. In practice, however, the framing factor may be much larger. According to the report prepared in 2002 by Enermodal Engineering for the California Energy Commission, residential walls in California have an average framing factor of 27%. A similar study performed by ASHRAE in 2003 found an average framing factor of 25% for all US residential buildings (CEC 2001A,CEC 2001B).

To better understand the interactions of different building envelope components the Whole-Wall Thermal Evaluation Procedure was developed (Kosny, Desjarlais 1994). The "Whole-Wall Procedure" has been used to estimate the opaque

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wall R-value (whole-wall R-value), independent of the type of wall system and construction materials.

The following list of thermal performance terms were introduced:

Center-of-cavity R-value: Sum of wall material R-values calculated at a point in the center of a wall cavity. This R-value doesn't include framing materials.

Clear-wall R-value: R-value for the wall area containing only insulation and necessary framing materials for a region with no windows, corners, or connections between other envelope elements such as roofs, foundations, and walls.

Framing factor: Framing factor is the ratio of the area of all structural members (studs and top and bottom plates or tracks in case of steel framing) to the total wall area.

Interface details: A set of common structural connections between the exterior wall and other envelope components, such as wall/wall (corners), wall /roof, wall/floor, window header, window sill, door jam, door header, and window jamb, that make up a representative residential wall.

Whole-wall R-value: R-value estimation for the whole opaque wall including the thermal performance of the "clear wall" area with insulation and structural elements and typical envelope interface details, including wall/wall (corners), wall /roof, wall/floor, wall/door, and wall/window connections.

In keeping with the data presented by California Energy Commission and ASHRAE reports, all wall assemblies in this report have framing factors close to 25% (CEC 2001A,CEC 2001B). It is well known that the presence of framing members (like wood or steel profiles) reduces the R-value of a wall system. The measure of this effect is known as the framing effect coefficient, f, of a wall, which is calculated using the following simple expression that contains clear-wall R-value, R_{cw}, and the center-of-cavity R-value, R_n.

$$f = \left[1 - \frac{R_{cw}}{R_n}\right] \cdot 100 \qquad (1)$$

The US residential construction market is dominated by wood-frame construction. Steel framing represents only a very small fraction of that market. However, steel-framed technologies offer many advantages like termite resistance, dimensional stability, and lightweight construction, and materials that can be recycled. The main disadvantage is the high thermal conductivity of steel. According to the American Iron and Steel Institute, steel-framed home construction has increased 300% in the US and Canada since 1998. (AISI]

Clear wall R-value (Kosny, Desjarlais 1994) is the most widely-used thermal performance measure of wall assemblies. Clear-wall R-value can be measured using a hot-box facility (ASTM 2006), and it represents R-value of the system of structural, insulating, and finish materials. ASHRAE 90.1 and 90.2, the International Energy Conservation Code (IECC), and Title 24 of the California Energy Commission (CEC) established energy performance standards for buildings (ASHRAE 19989, ASHRAE 1993, IECC 2003, ASHRAE 2001). These standards establish thermal performance requirements for building envelope components, which are more focused on in-cavity R-value, or nominal R-value of the insulation. For thermal calculations, the ASHRAE Handbook of Fundamentals (ASHRAE 2001) recommends using the parallel-path method for wood framing and the modified-zone method for steel-frame walls (Kosny, Christian 1995). CEC Title 24 thermal requirements for steel-frame wall assemblies are based on the zone method (ASHRAE 2001, Kosny, Christian 1995A). IECC standard requirements are based mostly on results of ASHRAE or DOE research projects. However, they are very often modified as a result of requests from companies producing different building materials, consulting companies, or trade associations. The common denominator for all prescriptive thermal requirements coming from ASHRAE, IECC, and CEC, is the fact that they all recognize only stud material, stud spacing, and stud depth. This leads to unrealistically low framing factors (9.4% for stud spacing 16-in. o.c. or *40-cm*, and 6.3% for stud spacing 24-in. o.c. or *61-cm*).

In the case of hot-box tests performed by North American labs, the high of the wall assembly is most-often 8-ft (2.44-m). The natural choice for the width of the wall specimen is 8-ft (2.44-m.), since it can accommodate both 16-in. and 24-in. stud spacing (41-cm. and 60-cm. respectively). The top and bottom plates (or tracks in case of steel framing) are part of the test specimens, which yields framing factors of 14% for stud spacing 16-in. (40-cm) o.c. and 11% for stud spacing 24-in. (61-cm) o.c. Figure 1 shows the traditional 8-ft by 8-ft (2.44-m by 2.44-m) wall assembly used by ORNL for hot-box testing.

During 2001 and 2003, CEC and ASHRAE projects estimated the framing factor in current low-rise residential buildings (CEC 2001B,Carpenter, Schumacher 2003). It was found that in Californian low-rise residential buildings approximately 27% of the total wall area is occupied by framing and the average framing factor in walls nationwide is approximately 25%. This number includes the framing used around windows and doors, structural reinforcement, and corners framing. In the case of wood framing, this means that in California, 27% of the opaque wall area is made of solid wood.

The Residential Energy Services Network (RESNET), which is widely-used for design and code-approval purposes, does not address the intense thermal bridging generated by architectural and structural components with increased amount of framing members as well as insulation imperfections (RESNET 2003). Building load calculation programs like Manual J (Rutkowski 2005) don't incorporate these thermal anomalies. Previous ORNL research demonstrated that about 10 to 15% of the US residential energy consumption is generated by thermal bridging (about 0.8 Quad a year), which is not normally included in building loads analysis, sizing HVAC equipment, and whole-building energy consumption calculations (Kosny, Christian 1995B, Kosny, Syed 2004). In this paper, this theoretical gap is addressed for most common wood and steel-framed wall technologies.

Figure 1 *Wood stud wall assembly typically used for hot-box testing. The size of the test wall is 8 × 8 ft (2.4 × 2.4 m).*

THERMAL EFFECTS OF FRAMING

In general, assuming that thermal insulation perfectly fills wall cavities, the thermal effect of framing is a function of the density of framing installation (stud spacing), ratio between thermal conductivities of cavity insulation and framing material, and the depth of the wall cavity. In reality, any expectations regarding a perfect installation of the cavity batt insulation are unrealistic, especially in areas where insulation has to fit non-standard-sized wall cavities. In North America framing members have relatively uniform sizes (1.-1/2-in. or 1-5/8-in. – *3.8-cm or 4.1-cm, respectively*).

For wood-stud walls without foam-sheathing the authors propose the following method of estimating whole wall R-values: To estimate Whole-Wall R-value of a wood frame wall, for each % of the wall framing reduce the nominal center-of-cavity R-value by 1%. This method permits a quick and relatively accurate estimate of the whole-wall R-value from known center-of-cavity R-value and the framing factor.

To envision the effects of framing on the wood stud wall R-value calculations, Table 1 shows %-differences from the basic cases (with only studs included in the calculation) and two wall configurations of different framing factors. The analyzed wood frame wall is constructed with ½-inch (1.3-cm) thick gypsum board on one side, ½-in. (1.3-cm) thick OSB (Oriented Strand Board) on the other side, and R-13 (2.3 m^2K/W) cavity insulation. It can be seen that R-value difference between wall configurations currently used for hot-box testing (14% of framing) and more realistic walls containing 25% of framing is close to 15%. This fact leads to the conclusion that the framing factor for a hot-box test should reflect current construction practice. For steel-framed assemblies, due to more complex character of heat transfer, such simplified calculations are not possible. However, similar differences in R-values may easily exceed 30% for different levels of framing.

A DOE-2.1 whole-building energy modeling exercise was performed to demonstrate a magnitude of potential differences in heating and cooling loads' calculations performed for a 1500 ft^2 (140 m^2) one-story house located in Atlanta, GA or Minneapolis, MN. For each location, two options of wall R-values were considered. First option with R-value of R-12.7 h·ft^2·°F/BTU (2.24 m^2K/W) in Table 1 represents a 9.4% framing factor. For the second option a wall with 25% of framing the R-value is R-10.5 h·ft^2·°F/BTU (1.85 m^2K/W).

The results of a series of DOE 2.1E whole-building energy simulations, for the house located in Atlanta, showed about 17% difference in annual heating loads generated by walls, and similarly about 18% difference in cooling loads – as discussed above, wall R-values of R-12.7 h·ft^2·°F/BTU (2.24 m^2K/W) and R-10.5 h·ft^2·°F/BTU (1.85 m^2K/W). For Minneapolis, the annual heating loads generated by walls were 15% different, and the difference for the cooling loads was about 18%.

Qualities of construction and insulation installation play important roles as well. It is well known that poorly installed cavity insulation can significantly impair the thermal performance of building envelope components. One of the most common problems in residential construction industry is installation precision of structural members. It is very common to find studs offset by ± 1 inch (2.5-cm), or locations where some structural members are misplaced, twisted, or buckled under structural, moisture, and thermal loads. These imperfections are not important for loose-fill or spray-applied insulations. They represent a significant challenge for building envelopes insulated with factory-made batts, which are commonly found products in the US residential market. For 16-in. (40-cm) wood framing, factory-made batts are available in regular widths of 14-1/2 (36.8-cm) in and for steel framing oversized batts of 16 in.(40-cm) width are produced. Similarly for a 24 in. (61-cm) o.c. assemblies, 22-1/2-in (57.1-cm) regular size and 24-in.(61-cm) oversized batts are available. For locations with different than nominal stud spacing, batts have to be precut to the size of the wall cavity. In field conditions, this work is not always precise. That is why it is very common to find either un-insulated air pockets or compressed insulation batts. It is important to know that the insulation material industry is trying to overcome these problems by introduction of additional non-standard batt sizes and different installation strategies.

HOT-BOX TESTING OF WALL ASSAMBLIES WITH 24% FRAMING FACTOR

In an effort to measure the effects of framing on wall R-value, a series of hot-box experiments were performed on wood and steel frame assemblies. Three configurations of nominal 2x4 inch (5.1x10.2-cm) wood and steel-frame walls insulated with R-13 h·ft^2·°F/BTU *2.3 m^2K/W* (3.5-in. thick *8.9-cm*) fiberglass batts were tested in accordance with ASTM C 1363. These walls were constructed with 2x4 wood or steel

Table 1. Comparison of Approximate R-Values and Framing Factors for Nominal 2 × 4 in. (5.1 × 10.2 cm) Wood Stud Walls

In Series R-14[1]	Only Studs Included (Base Case)		Studs and Plates Included			Fictitious Wall with 25% Framing Factor		
Stud Spacing	Framing Factor	R-Value, $h \cdot ft^2 \cdot {}^oF/Btu$	Framing Factor	R-Value $h \cdot ft^2 \cdot {}^oF/Btu$	% Difference	Framing Factor	R-Value $h \cdot ft^2 \cdot {}^oF/Btu$	% Difference
16-in.	9.4%	12.7	14.1%	12.0	5.2%	25.0%	10.5	17.2%
24-in.	5.2%	13.3	11.0%	12.5	6.1%	25.0%	10.5	20.9%
		m^2K/W		m^2K/W			m^2K/W	
40-cm	9.4%	2.24	14.1%	2.11	5.2%	25.0%	1.85	17.2%
61-cm	5.2%	2.34	11.0%	2.20	6.1%	25.0%	1.85	20.9%

R-value calculated in the center of wall cavity (without considering framing members) was R-14 (2.46 $m^2 \cdot K/W$)

studs installed 16-in. (40-cm) o.c. The framing factors for all these wall assemblies were slightly greater than 24%. During these hot box tests, temperature differences across these test walls were between 40 to 45 ºF (4.4 -7.2 ^oC) with the mean temperatures close to 75 ºF (23.8 ^oC).

As shown on Figure 2, the top and bottom plates, clusters of studs, and horizontal bracing were included in the test specimens. R-13 *2.3* (2.3 m^2K/W) fiberglass batts were carefully cut to fill wall cavities without compression. Wall surfaces were finished with ½-in. (1.3-cm) thick gypsum boards and OSB sheathing. The first test wall was constructed with nominal 2x4 in. (5.1x10.2-cm) wood studs. In the second and third walls standard C-shape 3.5-in.(5.1-cm) 16-ga. light-gage steel framing was used. The third wall was similar to the second wall with the addition of ¾-in. (1.9-cm) thick expanded polystyrene foam sheathing on the exterior side of the steel studs. Test results are summarized in Table 2.

As shown in Table 2, in all tests, nominal center-of-cavity R-values were significantly larger than the test-generated clear-wall R-values. The first and second walls had the same center-of-cavity material R-values. The hot-box clear-wall R-value results, however, were 30% to 60% lower than the center-of-cavity R-values. These measurements show that center-of-cavity R-values are a poor representation of the whole-wall thermal performance. In that light they shouldn't be directly used for code approvals, load calculations, or whole-building energy simulations.

Many builders using light-gage steel framing believe that addition of ¾-in. (1.9-cm) thick XPS foam sheathing will increase the clear wall R-value to the level of similar wood frame walls. This series of hot-box tests showed that the addition of a ¾-in. (1.9-cm) thick XPS foam sheathing to the 2x4 (5.1x10.2-cm) steel-frame wall doesn't contribute enough thermal resistance to match the thermal performance of the 2x4 in. (5.1x10.2-cm) wood-frame wall insulated with the same type of R-13 (2.3 m^2K/W) fiberglass batt insulation.

different wall configurations from calculated heat fluxes

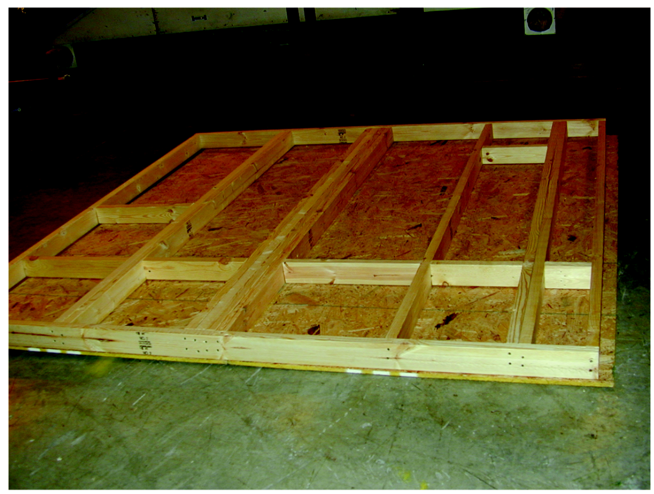

Figure 2 *Framing for wood stud wall assembly with 24% framing factor.*

NUMERICAL THERMAL ANALYSIS

In this work, various configurations of 2x4 wood and steel-framed walls were analyzed numerically for clear-wall R-values. The finite difference code, Heating 7.3, was utilized for this these calculations (Childs 1993). This code was calibrated using a number of standard wood and steel-framed wall systems and its accuracy is well documented. (Kosny, Desjarlais 1994, Kosny, Christian 1995B, Kosny, Childs 2002) In addition, the computer model was validated with the hot-box test results for the steel stud wall that were part of this project. Three-dimensional computer simulations were within 5% of the thermal measurements.

With the use of the calibrated computer model, each wall configuration was analyzed for steady-state heat transfer in three dimensions. Clear-wall R-values were calculated for the

through the systems.

Table 2. Hot-Box Test Results for Wood and Steel-Framed Wall Assemblies with Studs 16 in. (40 cm) O.C.

Wall Configuration	Wood Stud Wall Base 16 in. (40 cm)	Steel Stud Wall Base 16 in. (40 cm)	Steel Stud Wall 0.75 in. (1.9 cm) XPS
Clear Wall R (Hot Box Test) ($h \cdot ft^2 \cdot {}^\circ F/Btu$ [m^2K/W])	9.65 (1.69)	5.78 (1.02)	9.37 (1.65)
Center of Cavity R-Value ($h \cdot ft^2 \cdot {}^\circ F/Btu$ [m^2K/W])	13.95 (1.76)	13.95 (1.76)	17.95 (3.16)
% Difference in R-Values	30.8%	58.6%	47.8%

WALL CONFIGURATIONS USED FOR THERMAL ANALYSIS

A series of finite difference simulations were performed on 2x4 (5.1x10.2-cm) wood and steel-framed walls. The first wall specimen was a copy of the framing configuration which is traditionally used in hot-box testing. As shown on Figure 3 the test specimen contains wood studs installed 16-in. (40-cm) o.c. with single top and bottom plates. This wall has a framing factor of about 14%.

At the present time, several state energy authorities are considering incorporation of findings of the 2002 CEC and 2003 ASHRAE studies (CEC 2001A,CEC 2001B) into the local energy performance requirements. Unfortunately, many of these codes only characterize requirements for cavity insulation or a R-value/U-value through the insulation without consideration of the framing intensity or framing materials. It is a very incomplete approach! As shown in Table 2, two walls of the same in-cavity R-values may have significantly different clear wall R-values.

The amount of framing counts in thermal performance analysis. That is why new recommendations are needed for framing material configurations in hot-box testing - to incorporate framing factors of 25% or more. To study increased levels of framing within 8-ft. by 8-ft (2.44-m by 2.44-m) test walls, six wall configurations (three wood-frame and three steel-frame walls) were analyzed to determine the effect of stud placement on the clear-wall R-value calculation. These configurations are shown in Figures 4, 5, and 6.

Figure 4 shows example of the wall, where studs are centrally located. A cluster of 14 studs is located in the center of the wall. This type of configuration is common among whole-building energy modelers since it is easy to represent any framing factor by adjusting the width of a single region.

Figure 5 shows a configuration where studs are evenly distributed across the wall area. The wall shown in Figure 6 is more realistic. It contains several horizontal members, two four-stud clusters, and two double-stud clusters. This wall configuration is probably the best representation of current structural framing practice in residential buildings of the three shown (Chini, Gupta 1997).

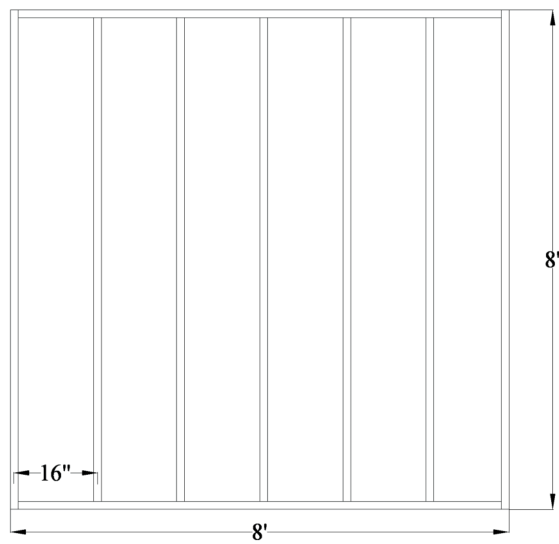

Figure 3 *Schematic of an 8 × 8 ft (2.44 × 2.44 m) test wall with 16 in. spacing.*

Figure 7 shows a wall configuration with 14 studs centrally located. There are 2-in. gaps between each two of centrally-located studs. This configuration was used to analyze the effects of missing insulation in areas of high concentration of structural members.

On the wall configuration as presented on Figure 7, spaces between studs can be empty or filled with the insulation. To further evaluate the effect of a series of these 2-in. (5.1-cm) wide spaces between individual studs, five walls (two wood stud and three steel stud configurations) were studied as shown on Figures 8-a. through 8-e. These configurations represented different options in installation of insulation. This analysis is very important for situations where fiberglass batt insulation is in use. For small cavities fiberglass batts have to be individually measured, cut, and installed. Since it is a very labor-intensive process, builders sometimes leave such small air-spaces without insulation.

To enable comparisons between all wall configurations presented on Figures 4 through 8, the following characteristics were maintained in computer modeling:

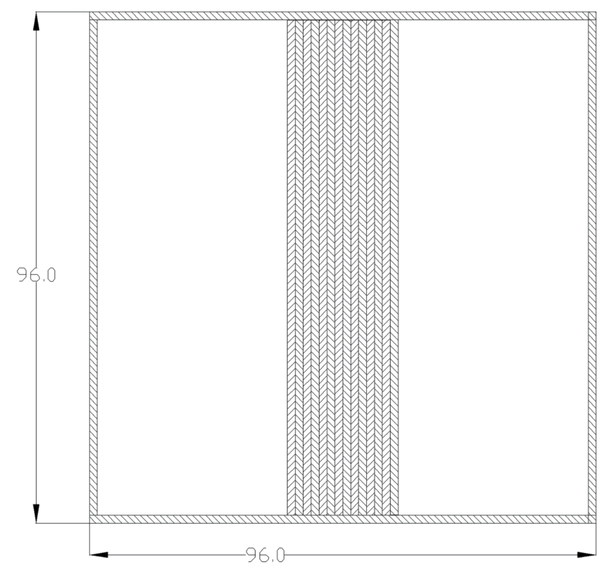

Figure 4 *Centrally located studs for a 27% framing factor at 8 × 8 ft (2.44 × 2.44 m) wall.*

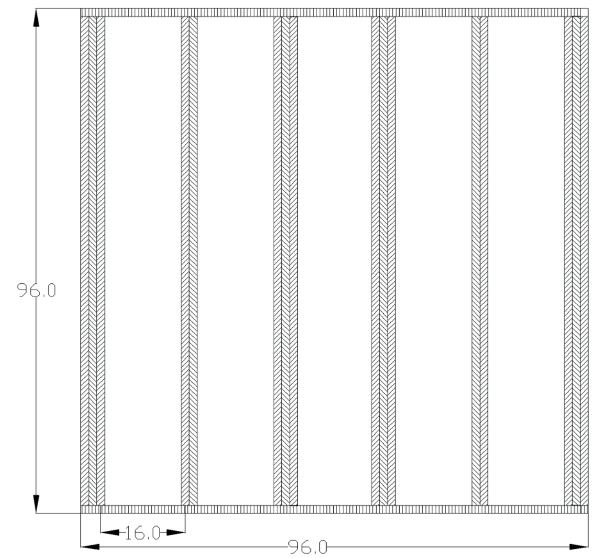

Figure 5 *Equally distributed studs with 16 in. (40 cm) o.c. for a 27% framing factor.*

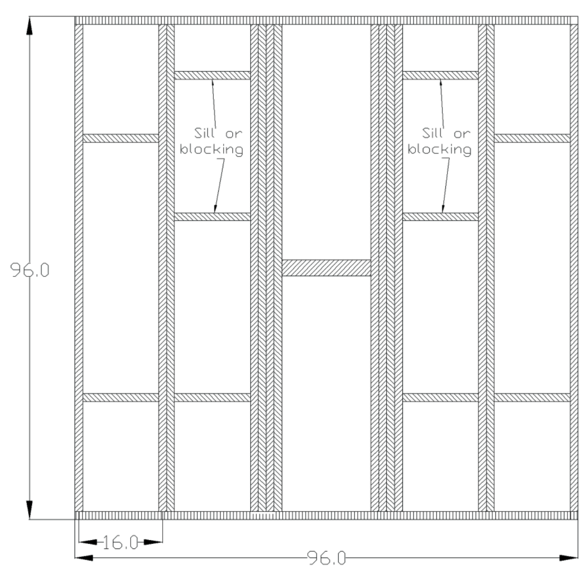

Figure 6 *Stud distribution with a 27% framing factor at th 8 × 8 ft (2.44 × 2.44 m) wall.*

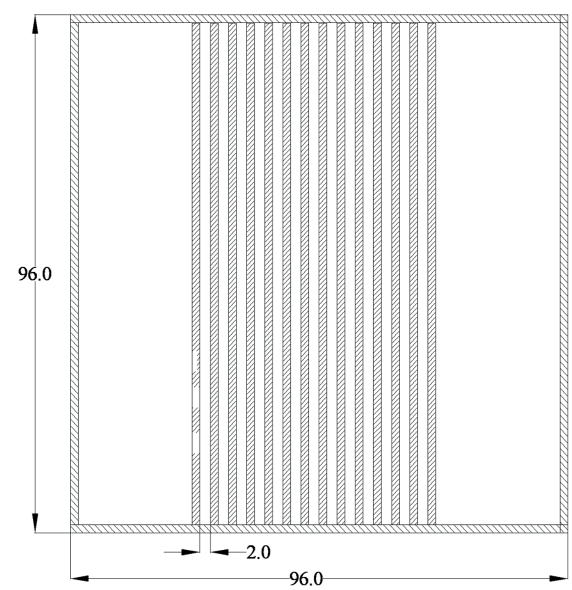

Figure 7 *Schematic of distributed studs with 2 in. (5.1 cm) gaps and a 27% framing factor at the 8 × 8 ft (2.44 × 2.44 m) wall.*

1. 27% framing factor.
2. Walls are 8-ft. by 8-ft. (2.44-m by 2.44-m)
3. Interior wall finish is 5/8-in. (1.6-cm) gypsum.
4. Exterior wall sheathing is 7/16-in. (1.11-cm) OSB board.
5. Wood siding is applied on the exterior side.
6. R-11 fiberglass batts are used for cavity insulation.
7. In case of wood frame configurations, nominal 2x4-in (5.1x10.2-cm). – 16-in. (40-cm) stud spacing is used.
8. In case of steel-framed configuration, conventional 3.5-in. (8.9-cm) C-shape steel studs are used with 16-in. (40-cm) spacing.

RESULTS OF COMPUTER MODELING AND DISCUSSION

A series of finite difference simulations were performed on the wall configurations pictured in Figures 4 through 8. Clear-wall R-values for individual wall configurations were computed. It was observed from this analysis that even though the percentage of framing was the same in all walls (framing factor 27%), calculated R-values varied. For all of these

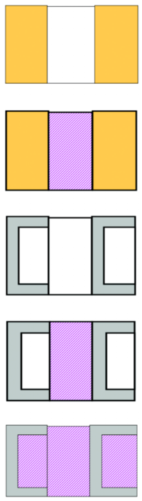

Figure 8.a. Wood Studs with Two-Inch Gap

Figure 8.b. Wood Studs with Two-Inches of Insulation

Figure 8.c. Steel Studs with a Two-Inch Gap

Figure 8.d. Steel Studs with Two-Inches of Insulation

Figure 8.e. Steel Studs with Insulation in the Frame

Figure 8 *Wood and steel stud configuration used in thermal modeling.*

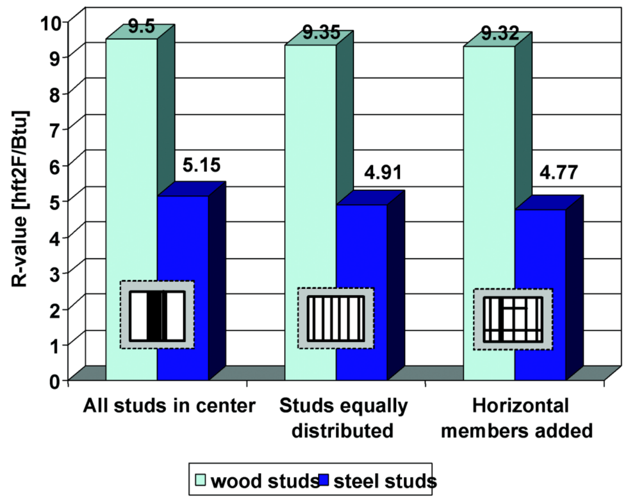

Figure 9 *Comparison of R-values for three wood and steel-framed walls (from Figures 4–6).*

configurations, the nominal R-value calculated for the center of cavity was about R-13. The framing effect coefficients were calculated using Equation 1 and presented in Table 3 and Figure 9.

As shown on Figure 9, the R-value variation was only 2%. In the case of steel frame walls this variation was about 8%. The ratio of the steel stud wall R-values to the R-values of wood stud walls averaged 0.47. The framing effect coefficient in steel-framed assemblies averaged 62%, while the wood-frame walls averaged 28%. It can be seen from these results, that light-gage steel structures can not be designed based on the one-by-one replacement method using blueprints developed for the wood frame houses. The use of steel framing should be at least combined with insulating sheathing as recommended by the American Iron and Steel Institute (Chini, Gupta 1997, AISI 2003).

Wall configurations with studs installed in large clusters, are commonly utilized in whole-building energy simulations, due to the fact that it is very simple to represent any amount of framing in that way. The data presented above demonstrate that this method can be used for wood-frame walls. Unfortunately, it is not true in case of steel framing, where heat transfer is more complex.

A series of additional simulations was performed to estimate sensitivity of the clear wall R-value to the imperfections in installing cavity insulation. The installation of insulation in buildings is not always carried out as carefully as it is done in laboratory conditions. Wall studs are often off-center by an inch or two. High concentrations of framing members create spaces where batt insulation has to be custom cut and fit. At the same time these batts are not always cut precisely to fit the cavity. This problem doesn't exist when loose-fill insulation or sprayed foam are used.

Five additional wall models were developed to estimate the effect of imperfections in installation of cavity insulation. These wall assemblies are depicted in Figures 8a through 8e. In these wall assemblies small air gaps between studs are either un-insulated, or filled with insulation. An additional case was considered for steel stud assemblies where the full space between stud flanges was also filled with insulation – as shown in Figure 8e.

The results presented in Figure 10 show that wood-frame walls are very sensitive to imperfections in installation of the cavity insulation. In case of the wood stud wall containing two-inch air gaps between individual studs, the R-value was only R-5.65 h·ft^2·°F/BTU (*0.99 m^{2}K/W)***.** The framing effect coefficient for this wall configuration was 56%. That is very close to framing effect observed for steel-framed walls – see Table 3. When all these air gaps are filled with insulation, the wall R-value increases to R-9.24 h·ft^2·°F/BTU (*1.63 m^{2}K/W)*. This is a 64% improvement.

In the case of steel framing, the sensitivity to imperfections in insulation installation is significantly lower. In wall configuration containing un-insulated two-inch gaps between studs, the R-value is 3.85 (*0.68 m^{2}K/W)*. When the gaps are partly-filled with insulation the clear-wall R-value is close to 4.17 (*0.73 m^{2}K/W)*. When gaps in the steel-frame wall are filled with insulation (as shown in Figure 8-e) the R-value is about 4.30 (*0.76 m^{2}K/W)*. The difference between lowest and highest R-values is in case of steel stud walls about 12%.

The five simulations presented in Figure 10, helped to demonstrate how important good quality installation of the insulation is. Thermal performance of wood stud walls can be dramatically changed with the presence of air gaps in stud cavities. It is good to realize that in currently-built residential houses, due to intense framing, about 30% to 40% of the wall

Table 3. R-Values and Framing Effect Coefficients for Three Wall Configurations from Figures 4–6

Type of Configuration	Clear-Wall R-Value, h·ft²·°F/Btu (*m²·K/W*)		Framing Effect Coefficient, %	
	Wood	Steel	Wood	Steel
All Studs in Center (Figure 4)	9.50 (1.67)	5.51 (0.97)	26.9	57.6
Equally Distributed (Figure 5)	9.35 (1.65)	4.91 (0.86)	28.1	62.2
Equally Distributed Plus Header and Sill (Figure 6)	9.32 (1.64)	4.77 (0.84)	28.3	63.3

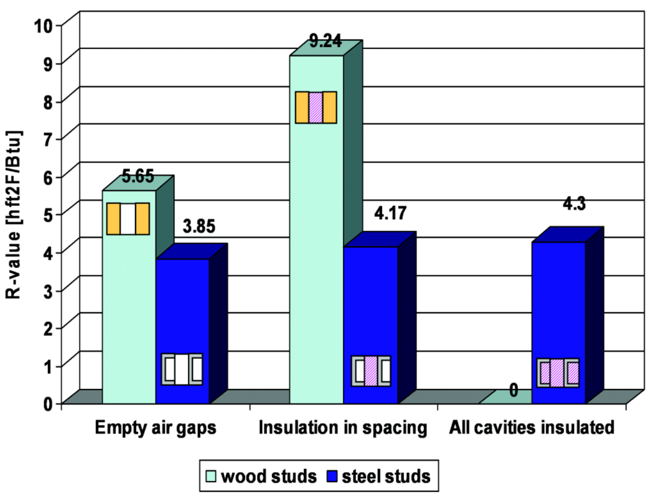

Figure 10 *Calculated clear-wall R-values for wood and steel-framed walls.*

cavities do not follow nominal framing spacing and require custom cutting and fitting of the batt insulation. Possible solutions to this problem involve application of blown-in-place cellulose, blow-in fiberglass insulation, or spray-applied foam.

CONCLUSIONS

This paper presents experimental and numerical analysis of thermal effects of framing intensity on overall wall thermal performance in wood and steel-framed walls. In addition, consequences of installation imperfections in cavity insulation were analyzed from a thermal perspective. A series of hot-box tests and computer simulations were conducted on wall assemblies representing current residential construction practice with 24% and 27% framing factors. The following conclusions can be derived from this work:

- Center-of-cavity R-values are significantly higher from the measured clear-wall R-values. The authors suggest that they shouldn't be directly used for code approvals, load calculations, or whole-building energy simulations.
- The addition of a ¾-in. (1.9-cm) thick extruded polystyrene foam board to steel-frame walls had a measured clear-wall R-value less than that of a similar wood-frame wall without foam-board sheathing.
- Wood-framed structures are less sensitive to differences in framing configuration intensity then steel-framed structures.
- Wood-frame walls are more sensitive than steel structures to imperfections in the wall-cavity insulation. If small air cavities between wood structural members are left un-insulated, the overall wall thermal performance can be compromised almost to the level of steel-framed walls.
- Thermal insulation installed in the internal areas between steel-stud flanges doesn't bring significant improvements of the steel-stud wall thermal performance.

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