New Developments in Mitigation of Thermal Bridges Generated by Light Gage Steel Framing Components

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KEYWORDS: *Thermal Bridges, R-Value, Steel Framing, Wall Construction*

SUMMARY:
While using metal instead of wood in framed structural components of buildings has some advantages, very strong thermal bridges caused by highly conductive steel studs degrade the thermal performance of such walls. For this reason, in many regions like North America and Scandinavia, wood framing is still a dominant technology for residential buildings. For metal studs several wall configurations have been developed to improve the thermal performance. The authors try to evaluate some of these wall systems. Three-dimensional finite difference computer simulations are used to analyze typical steel stud wall configurations. The simplest and most common way to overcome this problem is to block the path of heat flow with insulation layers.

The paper analyzes different methods and materials to optimize the thermal performance of metal stud wall assemblies. With either substantial layers of conventional insulation, or by utilizing high-performance insulation (aerogel and VIPs) the thermal bridging effect of the studs can be significantly reduced.

1. Introduction

Steel structural members have many advantages over wood framing. Steel is more dimensionally stable than wood, therefore steel-framed buildings require fewer repairs during first months after construction comparing to conventional wood-framed assemblies. Additional advantage of steel structural members is fact that they are non-flammable. Also, steel is resistant to insect destruction, what makes this material especially attractive in areas of termite activity.

On the other hand steel members conduct heat extremely well and when steel framing sections penetrate through the insulation they cause thermal bridging. This can sharply reduce the effective thermal resistance of a wall, floor or roof. This is one of the reasons, the application of steel as a framing material in the U.S. residential building market is relatively low. The U.S. steel industry has noticed much more success on commercial building market, which is not as rigorous regarding thermal efficiency and energy conservation. For this reason, in many regions like North America and Scandinavia, wood framing is still a dominant technology for residential buildings. During the last four decades several companies around the world started to promote a low-gage steel framing for residential and commercial buildings.

The most common way to overcome this thermal shorts' problem is to block the path of heat flow or reduce the contact area between metal stud and adjacent components. Several material configurations and steel profile design improvements have been introduced to increase the thermal effectiveness of light gage steel frame structures. These options have included diminishing the contact area between the studs and the low-conducting sheathing, reducing the steel stud web area, replacing the steel web with a less conductive material, and placing foam insulation where the thermal bridging is most critical. Some of these improvements were inefficient, others were promising, but did not go far enough to generate significant improvements in thermal performance allowing wider application of steel-framed technologies.

2. Technologies to Reduce Thermal Bridging – an Overview

One measure of thermal efficiency of a wall assembly besides the thermal resistivity is the *Framing Effect f*, representing the R-value reduction generated by the framing members in framed wall technologies . The Framing Effect is defined as the percentage reduction of the centre of cavity thermal resistance of the wall caused by the framing. This recognises that heat flows are complex and the proportional effect of the frame will vary depending on different details.

$$f = 1 - \frac{R_{simulated}}{R_{theor.}} \cdot 100 \qquad (1)$$

Where $R_{simulated}$ is the overall R-value for the element including the effect of the framing and $R_{theor.}$ is the R-value through the insulation away from the steel stud. Thus, a low framing effect is desirable and suggests that the framing has a small overall impact on reducing the R-value of the assembly. While typical values for wood-framed walls are up to 22%, the Framing Effect for a 9.2 cm steel stud wall (using 1.3 cm layer of plywood sheathing on both sides) is 38% (Kosny 2007a).

2.1 Ridges and Dimples

Reducing the contact area between the stud flange and the sheathing material can increase the thermal resistance path between them. This can be done by utilising ridges and dimples in the stud flange area. These modifications can be realised in the production stage of metal studs (Barbour 1994, Trethowen 1988). Reductions of the stud flange contact areas can be made by the outward extrusion of the small protuberances (dimples or ridges) in the stud flange surfaces (see Figure 1). In such walls the sheathing material does not contact the stud flange, but only the surface of these protuberances on the flange area. Another way to reduce thermal bridges is the usage of distant spacers.

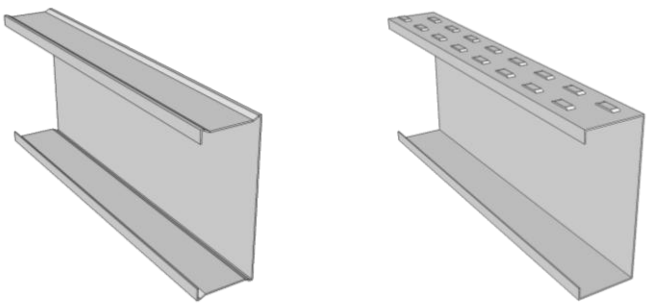


FIG 1. Reducing the contact area between metal stud and wall material can decrease the thermal bridging effect.

Vertical ridges reduced the contact area between studs and the sheathing material by about 95%. Thermal simulations on a 150mm stud wall with 13mm ridges shows that a 16% increase in U-value can be achieved compared with a conventional stud wall. In the case of a 90mm studs with 6mm ridges, an increase of about 9% is noted. The thermal effectiveness of the 13mm and 6mm ridges are similar (Kosny 2001).

Extruded dimples (height 0.25cm) can reduce the contact area between studs and the sheathing material by 89%. When comparing simulations of a traditionally constructed 89mm (3-1/2-in) steel stud wall with one with studs that had 2.5mm dimples it was found that the dimples reduced the framing effect from 39% to 33% and improved the conductivity about 8.7% (Kosny 1997-2).

2.2 Spacers and tapes

Spacers can be incorporated into the wall to separate the sheathing from the steel stud to create a cavity. This is usually achieved by installing horizontal steel or wooden furring strips between the studs and exterior sheathing. The increase in wall R-value of the assembly is close to the R-value of the additional air space or an improvement of about 20% (Strzepek, 1990).
Combined versions of metal stud walls with wood spacers (see figure 2, right drawing) lead to U-Values comparable to wood constructions or even better (Kosny 2002). However these designs are complex and more expensive.

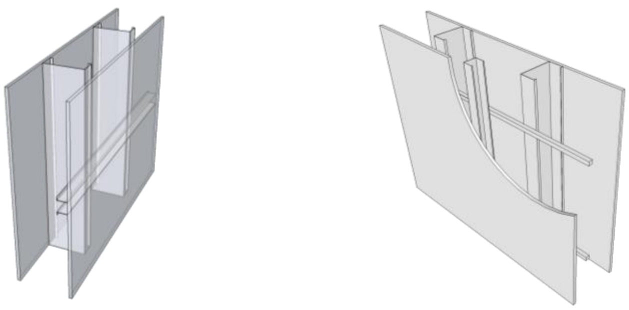


FIG 2. Metal or wood spacers reduce contact area. By combining two layers of steel studs with wooden spacers, the U-Values of the overall wall-assembly can be as good as - or even better than - a wooden construction.

2.3 Steel Stud Web

Most of the problems in steel-framed constructions are caused by the intensive heat transfer through the steel stud web. As depicted in Figure 3, improvements in thermal performance can be achieved by a reduction of the stud web area or replacement of the steel web by a less conductive material. Walls with reduced stud web are much more thermally efficient than walls with traditional studs. The reductions of thermal conductivity in typical wall constructions are up to 36%, the framing factor f can be reduced to 19% (41% increase compared to baseline assembly) (Kosny 2002)

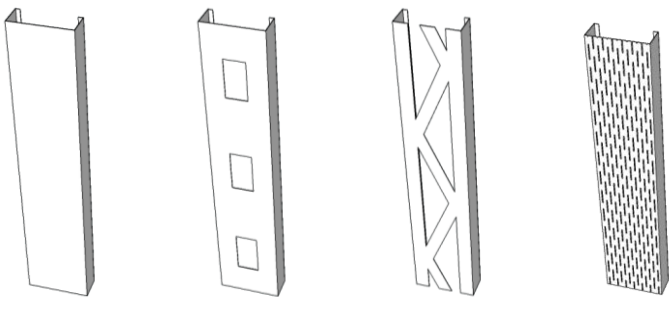


FIG 3. Standard metal stud (left) and different examples for reduced web area.

3. Numerical Comparisons of Advanced Wall Assemblies

To analyze the effects of thermal characteristics of used insulation on performance of different insulation techniques, five different wall assemblies are analytically compared. Table 1 to 5 list the layers the wall consists of, combined with an exemplary drawing. The assemblies were thermally simulated using three-dimensional finite difference computer code: HEATING 7.3.

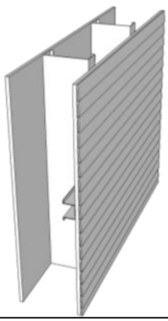
HEATING is a research-type, generalized 3-dimensional (3-D) heat conduction code developed by the Oak Ridge National Laboratory (USA) originally for designing of components for nuclear reactors. During 1990-ties, it was adopted to analyze building envelope assemblies. HEATING can solve steady-state and/or transient heat conduction problems in one-, two-, or three-dimensional Cartesian, cylindrical, or spherical coordinates. Multiple materials and time- and temperature-dependent thermal conductivity, density, and specific heat can be specified. The boundary conditions, which may be surface-to-environment or surface-to-surface, may be specified temperatures or any combination of prescribed heat flux, forced convection, natural convection and radiation. The boundary condition parameters can be time and/or temperature dependent. HEATING solves transient problems by using any one of several finite-difference schemes: Crank-Nicolson implicit procedure, classical implicit procedure, classical explicit procedure, or Levy explicit method (Childs 1993).

Three-dimensional computer modelling enabled analysis of the temperature distribution in the analyzed walls and precise calculation of local heat fluxes. For the modelling Surface-to-environment boundary conditions were utilized, with T_i=21.1°C (70°F) and T_e= -6.7°C (20°F).

3.1.1 Spacer with Hat Channel

This case implies a horizontal spacer; the cavity is filled up with different materials with increasing thermal resistivity, starting from typical values for blown in fibreglass insulation. U-Values up to 0.38 W/m²K can be reached, but the influence of the metal is still significant, as surface temperatures of a static heat-flow simulation show (see figure 4).

TABLE 1. Wall assembly A: from inside to outside: gypsum board, 8.9 cm metal stud, 2.5 cm horizontal spacer, OSB panel, wood sheeting.
Case 1 – 6: Different conductivity of insulation material filled in cavity.



Case	Conductivity of insulation material [W/mK]	Total U-Value of Wall [W/m²K]
1	0.048	0.60
2	0.042	0.55
3	0.036	0.51
4	0.029	0.45
5	0.024	0.41
6	0.021	0.38

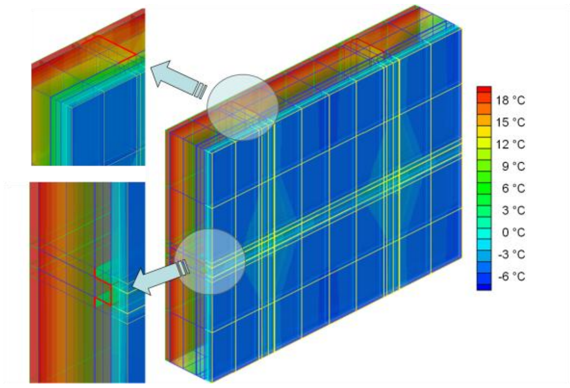
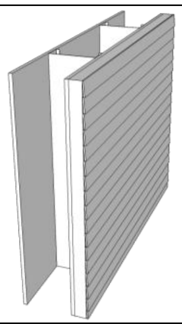


FIG 4. Simulation results for a wall assembly with horizontal hats to reduce contact area (case 3 in table 1). Thermal-bridge effects caused by the steel frames can be clearly seen on the surface.

3.1.2 Exterior Insulation

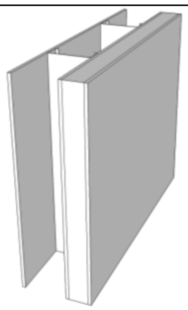
The next examples use external insulation, thus blocking the heat flow from the metal flange to the outside. Adding insulation on the outside can reduce the U-Value significantly. The increase in U-Values correlates first and foremost with the thickness of the insulation. On the other hand thicker layers of insulation bring up challenges in aspects of fixation of the layer itself and outside sheeting.

TABLE 2. Wall assembly B: from inside to outside: gypsum board, 8.9 cm metal stud, OSB panel, 5.1 cm foam insulation, wood sheeting. Cavity filled with fibreglass (k=0.039 W/mK). Case 1 – 4: Different conductivity of foam sheeting.



Case	Conductivity of foam sheeting [W/mK]	Total U-Value of Wall [W/m²K]
1	0.036	0.46
2	0.029	0.42
3	0.024	0.39
4	0.021	0.36

TABLE 3. Wall assembly C: from inside to outside: gypsum board, 8.9 cm metal stud, OSB panel,10.2 cm EIFS (exterior insulation finish system), plaster. Cavity filled with fibreglass (k=0.039 W/mK). Case 1 – 4: Different conductivity of foam sheeting.



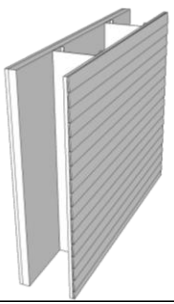
Case	Conductivity of foam sheeting [W/mK]	Total U-Value of Wall [W/m²K]
1	0.036	0.24
2	0.029	0.20
3	0.024	0.18
4	0.021	0.16

3.1.3 Aerrogel Insulation

Another promising material to reduce the heat-flow is using aerogel insulation. Aerogels are nano insulation materials of very low-density that exhibit extraordinarily low thermal and acoustic conductivities. Aerogels are usually made from gels where the liquid component of the gel is replaced with gas. Their unique physical properties include the highest thermal resistivity, the highest specific surface area, the lowest density, the lowest refractive index, and the lowest dielectric constant of all solid materials. These properties give aerogels the potential for a wide range of unique applications.

In this example the aerogel insulation layer is implemented as fiber-reinforced silica aerogel covered gypsum board (experimental determined U-Value aerogel: 0.014 W/m²K (Kosny 2007b)). This technique has increasing applications in retrofit projects where internal space is valuable and architectural restrictions do not allow an application of conventional exterior insulation.

TABLE 4. Wall assembly D: from inside to outsite: gypsum board, 2.5 cm / 3.8 cm aerogel insulation, 8.9 cm metal stud, OSB panel, wood sheeting. Cavity filled with fibreglass (k=0.039 W/mK). Case 1 – 2: Different thickness of aerogel insulation



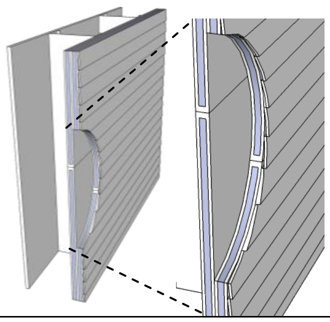
Case	Conductivity of aerogel insulation [W/mK]	Total U-Value of Wall [W/m²K]
1	0.014 (1.27 cm)	0.41
2	0.014 (2.54 cm)	0.29

The high thermal resistance of the aerogel has a significant influence on the thermal performance of the wall by adding only small amounts of thickness. This can be an issue especially for refurbishments or other situations with limited space.

3.1.4 Vacuum Insulation

The last example uses the insulation material with one of the highest commercially-available thermal resistivity. It is vacuum insulation. The vacuum panels are incorporated as sandwich elements, covered by a 0.64cm foam layers. On the sides the foam cover causes a 2.5cm gap at the joint area between two panels, where only the foam is effective as insulation layer (17% of the effective surface area). As counteraction two sandwich elements are stacked with an overlay of 20cm.

TABLE 5. Wall assembly D: from inside to outsite: gypsum board, 8.9 cm metal stud, two layers of foam-covered vacuum panels(thickness: vacuum panels: 3.8cm, foam cover: 0.6cm), 20cm overlay.



Case	Conductivity of vacuum panel incl. sheeting [W/mK]	Total U-Value of Wall [W/m²K]
1	0.003	0.06

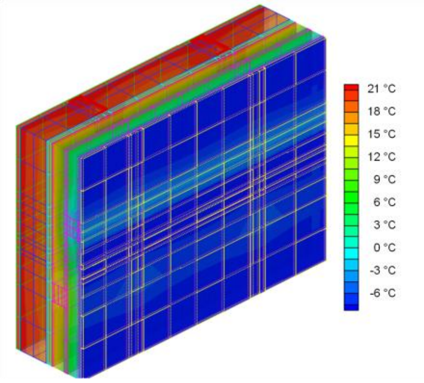


FIG 5. Visualization of simulation results for an assembly using vacuum insulation panels. Due to the low conductivity of the overall insulation layer the thermal bridging effect of the metal studs is nearly irrelevant. The only fluctuation that is seen on the outer surface is caused by the "foam-gap" between the vacuum panels.

Using vacuum insulation in the wall assembly not only leads to the lowest U-Values, it also masks the influence of the metal studs. While being an expensive solution at the present time, it can become more and more attractive, as soon as vacuum insulation gets to larger scale production and cost come down.

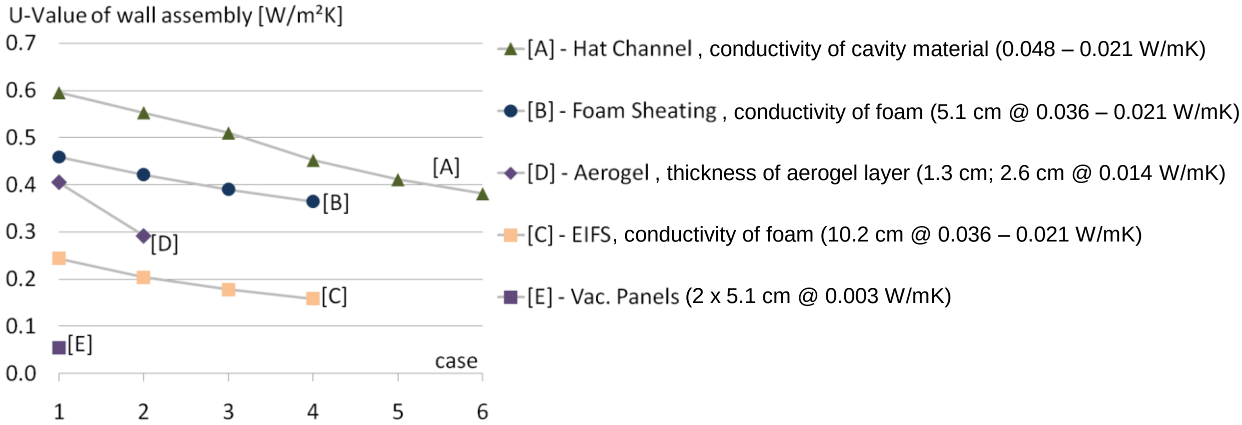


FIG 6. Graphical comparison of the different wall assemblies.

Figure 6 summarises the results from the simulations. It shows that low U-Values can be achieved by adding substantial insulation layers ([C]). If the amount of space is limited (for example in a refurbishment), materials like aerogel can lead to comparable results – with the disadvantage of being more expensive. The usage of vacuum insulation can be seen as an outlook: as soon as materials with very low thermal conductivity are available on economically acceptable scale. Simulation results demonstrated that the material of the structural framework is nearly irrelevant from thermal standpoint. In this case using metal studs has nearly no influence on the thermal performance of the wall construction.

4. Conclusions

The paper gives a short overview about measures to reduce thermal bridging in metal stud walls.

The most common way to reduce thermal bridge effects in steel framing is to block the path of heat flow or reducing the contact area between metal stud and adjacent components. In this paper several material configurations and steel profile design improvements were analyzed in order to increase the thermal effectiveness of light gage steel frame structures. These options have included diminishing the contact area between the studs and the low-conducting sheathing, reducing the steel stud web area, replacing the steel web with a less conductive material, and placing foam insulation where the thermal bridging is most critical.

The following five different wall assemblies were compared by simulation-based analysis of their overall U-Values as a function of used thermal insulation.

1. The results of numerical analysis show that low wall U-Values can be achieved easily by adding thick insulation layers on wall surfaces.
2. If the amount of space is limited or installation of exterior insulation is prohibited, materials like aerogel can lead to comparable results – with the disadvantage of being more expensive.
3. The usage of vacuum insulation can be seen as an outlook: as soon as materials with very low thermal conductivity are available on economically acceptable scale.

References

Barbour E., Godgrow J., Kosny J., Christian J.E. 1994, Thermal Performance of Steel-Framed Walls, NAHB Research Center

Childs K.W. 1993, “Heating 7.2 User’s Manual,” Oak Ridge National Laboratory Report ORNL/TM-12262

Kosny, J. 2001, Advances in Residential Wall Technologies - Simple Ways of Decreasing the Whole Building Energy Consumption. ASHRAE Winter Meeting

Kosny 2002, Kosny, J.; Childs, P., Making Steel Framing as Thermally Efficient as Wood, 13th Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, Houston, TX

Kosny 2007a, Kosny, J., Yarbrough, D., Childs, P., and Syed, A., 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, Thermal Performance of the Exterior Envelopes of Buildings X, proceedings of ASHRAE THERM X, Clearwater, FL

Kosny 2007b, Kosny, J., Petrie, T., Yarbrough, D., Childs, P., Syed, A., and Blair, C. "Nano-Scale Insulation at Work: Thermal Performance of Thermally Bridged Wood and Steel Structures Insulated with Local Aerogel Insulation, Thermal Performance of the Exterior Envelopes of Buildings X, proceedings of ASHRAE THERM X, Clearwater, FL

Strzepek, W. R. 1990, Thermal Resistances of Steel Frame Wall Constructions Incorporating Various Combinations of Insulating Materials, Insulation Materials, Testing and Applications, ASTM/STP 1030

Trethowen, H. A. 1988, Thermal Insulation and Contact Resistance in Steel-Framed Panels, ASHRAE Transactions, Vol. 94, Part 2