Thermal and Shear Wall Performance of Building Assemblies with Insulated Frames

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ABSTRACT

A technique for improving the thermal performance of lightweight steel- and wood-framed building assemblies is introduced in this paper. In this approach, rigid extruded insulation material is applied only to the framing members themselves (studs, plates, doubles, headers, etc.), effectively creating a composite member composed of insulation and structural framing. The depth of the envelope cavity is thereby extended by an amount that is equal to the thickness of the rigid insulation employed. The deepened cavity can then be filled completely with the designer's choice of insulation materials. The ASTM C 976 Thermal Performance of Building Assemblies test was used to verify the thermal benefits of this approach. This empirical result is then compared with two-dimensional computer heat transfer simulations. A series-parallel path discussion of insulated wood-framed assemblies is also presented in this paper. Finally, static shear wall performance of assemblies framed with insulated steel is evaluated.

INTRODUCTION

Thermal bridging is a well-known and often overlooked problem in light building construction. The recent growth of light gauge steel framing in new residential housing starts has raised the awareness of the thermal bridging problem. Although nearly all students of heat transfer have studied the problem of thermal bridging through wood framing members, this phenomenon is often ignored, oversimplified, or hidden in state and model energy codes.[1]

One popular method for solving this problem with steel framing is the use of insulating sheathing. By wrapping the entire opaque area of the structure in rigid insulating foam, the effects of the steel thermal bridges can be mitigated (AISI 1995; *Energy Design Update* 1997). The rigid materials generally used for these systems, extruded polystyrene and polyisocyanurate, have high economic and environmental costs relative to other insulation materials. Furthermore, foam insulation systems applied exterior to structural sheathing (OSB, plywood, etc.) present practical problems and constraints related to the selection of exterior wall finishes.

Two alternative techniques to exterior insulation sheathing include (1) installation of horizontal resilient metal furring and (2) application of insulated tape along the framing members. The furring strip method reduces the amount of thermal bridging but does not eliminate the direct framing material heat pathways. Furthermore, the furring strip method makes it difficult to completely fill the assembly cavities with batt-type insulations such as fiberglass. The insulated tape does not perform very well in practice because of the compressibility limitations and the amount of labor required for installation.

This paper presents a new technique for combating thermal bridges in all types of stick-framed building envelopes, both steel and wood framing included.

This technique is based on an optimal material placement strategy. By placing rigid insulation only along the building's frame, significant reductions in bridging effects can be achieved. Additionally, the quantity of rigid foam utilized can be reduced by 75% to 80%, depending on the quantity of framing used (framing factor). By insulating the frame as well as

1. The 1995 Model Energy Code (MEC), for example, assumes a standard 25% framing factor for 61-inch-on-center framed walls and a 22% framing factor for 24-inch-on-center framing. It simplifies assemblies by modeling all ceilings (those with and without attics above) the same with a 7% framing factor using 2-by-4 truss chords spaced 24 inches on center and a 4/12 roof slope. It does allow a difference for raised truss design but keeps all other variables constant (Connell et al. 1996).

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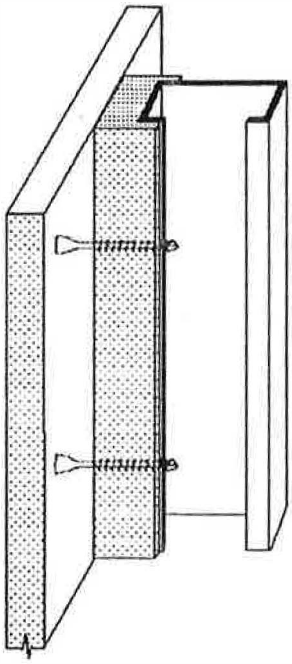

Figure 1 *Screw installation of wallboard or sheathing into an insulated steel C-section assembly.*

the cavities, this system enables builders to achieve a more contiguous level of insulation.

The rigid insulation can be applied to the interior, exterior, or both sides of the framing members. When installed on the exterior frame surface of a diaphragm shear wall assembly, rigid sheathing board such as plywood and oriented strand board (OSB) can be applied on top of the rigid insulation. This is different from conventional assemblies where the rigid insulation is applied exterior to the structural sheathing. Shear wall resistances comparable to the uninsulated shear wall assemblies can be achieved by increasing the fastener wire diameter. Figure 1 illustrates an insulated steel C-section stud with screws connecting the wallboard or sheathing. The compressive resistance of the insulator combines with the holding force of the screw to create an integrated structural assembly that can effectively resist shear loads. Figure 2 illustrates a header detail with and without rigid insulation applied to the frame.

Hot-Box and Simulation Results with Metal Studs

The *ASTM C 976-90 Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box* was conducted to evaluate the performance of a 2-by-4 nominal (1.625 in. by 3.625 in. actual, 41.275 mm by 92.075 mm) steel stud assembly with 2 in. (50.8 mm) of extruded polystyrene rigid insulation strips applied to the frame. The assembly details were:

- ½ in. (12.7 mm) drywall
- 3 5/8 in. (41.3 mm), 18 gauge studs 24 in. (609.6 mm) on center
- R-19 (h·°F·ft^2)/Btu (R-3.46 [m^2·K]/W) rated R-17.6 (h·°F·ft^2)/Btu at 5.5 in. or 3.10 (m^2·K)/W fiberglass batts
- 2 in. (50.8 mm) extruded polystyrene (R-10 [h·°F·ft^2]/Btu or R-1.761 [m^2·K]/W) rigid insulation strips along the exterior (cold side) of the studs and tracks
- 7/16 in. (11.1 mm) OSB (oriented strand board)

The test specimen dimensions were 8 ft high by 8 ft wide (2.44 m by 2.44 m). The test was performed at a 45°F (280.4 K) mean temperature, 70.1°F (294.3 K) air temperature on the drywall side, and 19.9°F (266.4 K) on the cold OSB side. Although industry commonly uses 50°F (283.2 K) and 100°F

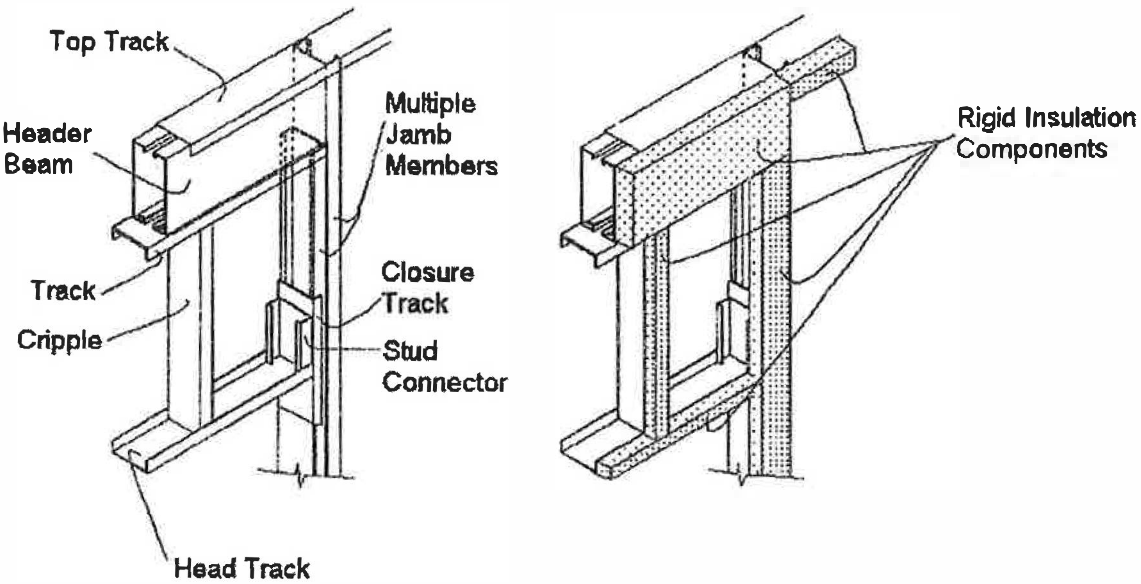

Figure 2 *A light gauge steel header construction detail before and after application of rigid insulation components.*

(310.9 K) boundary conditions with a mean temperature of 75°F (297.0 K), the ASTM C-976 test specifies that the boundary conditions should attempt to reproduce the normally occurring indoor and outdoor conditions. For this reason, we selected indoor and outdoor design conditions to resemble winter heating conditions in northern climates. It should be noted that the thermal conductivity of materials typically decreases with temperature, and a higher assembly conductance is expected at a 75°F (297.0 K) mean temperature. The surface-to-surface thermal resistance was 15.3 (h·°F·ft^2)/Btu (2.69 [m^2·K]/W); including air films, this was 16.1 (h·°F·ft^2)/Btu (2.84 [m^2·K]/W). The air-to-air thermal transmittance was 0.063 Btu/(h·°F·ft^2) (0.358 W/[m^2·K]). This result was estimated by the testing agency to have an uncertainty of less than 5% based on a propagation of errors analysis augmented by interlaboratory test comparisons and reference material repeatability tests. For comparison purposes, consider the previously tested overall resistance value for a 1.625 in. by 6 in. (41.275 mm by 152.400 mm), 18 gauge steel stud assembly, 24 in. (609.6 mm) on center, R-19 (h·°F·ft^2)/Btu (R-3.46 [m^2·K]/W) fiberglass batts, ½ in. (12.7 mm) plywood, 1 in. (25.4 mm) of extruded polystyrene full sheet insulation (AISI 1995). This wall had an air-to-air thermal resistance of 16.2 (h·°F·ft^2)/Btu (R-2.853 [m^2·K]/W) under the same test conditions.

The ASTM C976 thermal performance test result was compared to the performance predicted using THERM 1.0, a public domain two-dimensional heat transfer software program (LBNL 1996). The simulation of the tested wall assembly predicted an air-to-air thermal resistance of R-16.4 (h·°F·ft^2)/Btu (R-2.89 [m^2·K]/W), a 1.9% deviation from the hot box result. Using the simulation tool, it is extremely easy to modify the assembly details. Figures 3 and 4 show simulation results in terms of isothermal planes and temperature contour plots of this assembly with the rigid insulation strips placed on the warm side of the wall, directly beneath the drywall. This simulation was run using 70.1°F (294.3 K) and 19.9°F (266.4 K) boundary conditions. The simulation calculated a thermal resistance of 16.5 (h·°F·ft^2)/Btu (R-2.91

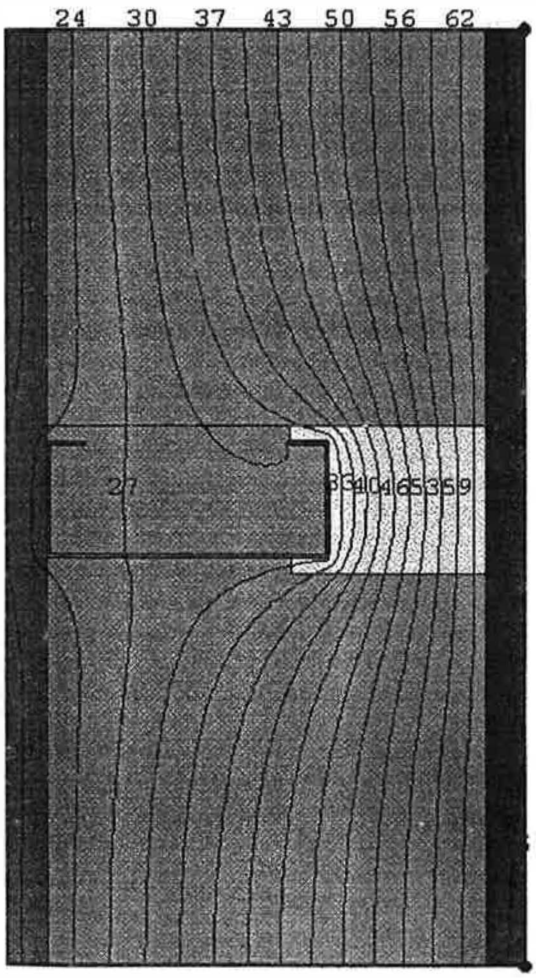

Figure 3 *Isothermal planes view of a two-dimensional heat transfer simulation of a 1.625 in. by 3.625 in. (41.275 mm by 92.075 mm) steel stud assembly insulated with 2 in. (50.8 mm) of extruded polystryrene (XPS) rigid insulation strip to the interior side.*

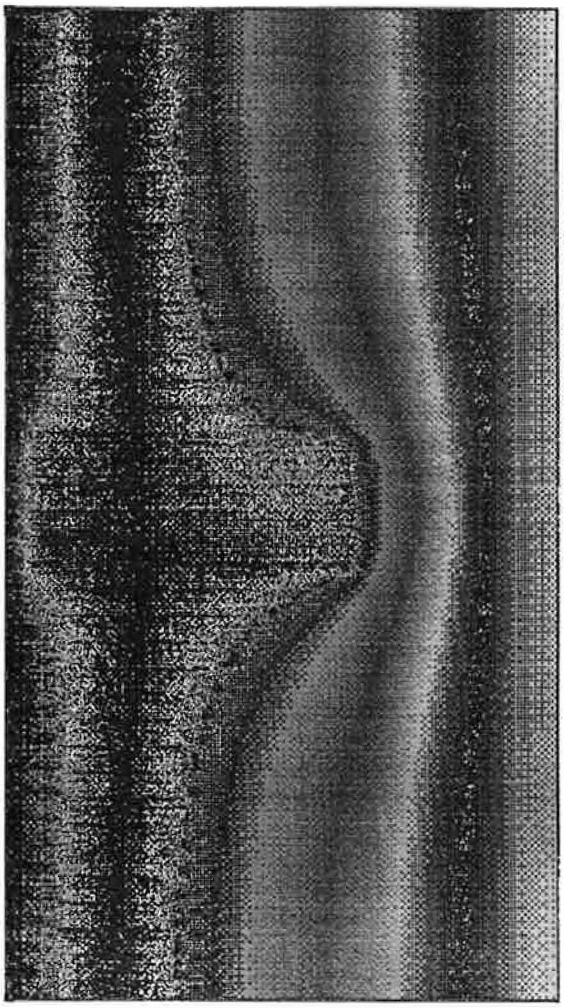

Figure 4 *A temperature contour plot of the same insulated steel stud assembly that is illustrated in Figure 3.*

[m^2·K]/W). This demonstrates that from a thermal conductivity perspective, the insulation strip method works equally well when it is placed on the interior frame surface as it does when placed on the exterior surface of the frame.

The Series-Parallel Heat Flow Model with Wood Studs

For building assemblies that do not contain highly conductive elements, the series-parallel heat flow model is the most widely used method for calculating the overall thermal transmittance of a building assembly (ASHRAE 1997). Material conductivities of the materials used in Tables 1a, 1b, 2a, and 2b are design values reported at 75°F (297.0 K) mean temperature (ASHRAE 1997).

These calculations show that by simply extending the building envelope cavity to match the cavity insulation's rated thickness yields effective opaque wall R-values greater than or equivalent to the maximum rated value of the cavity insulation (assembly 1, 2, and 3 in Table 2). When a 2×4 (38.1 mm × 88.9 mm) stud is insulated with 2 in. (50.8 mm) of extruded polystyrene, the overall thermal resistance of the assembly is increased to R-19.5 (h·ft^2·°F)/Btu (3.43 [m^2·K]/W). This represents an 11% increase over the cavity insulation resistance rating (R-17.6 [h·ft^2·°F]/Btu or 3.10 [m^2·K]/W) and a 23% increase over the resistance of the standard 2×6 (38.1 mm ×152.4 mm) wall assembly (R-15.9 [h·ft^2·°F]/Btu, 3.43 [m^2·K)/W]).

Shear Wall Performance of Rigid Foam Insulation on Metal Studs

To determine the impact of a foam surface on the shear value of a wall assembly, static tests were conducted earlier this year at a university. In these tests, we varied the screw fastener schedule, fastener size and head diameter, and the thickness and compressive resistance of the extruded polystyrene insulation. The tests were performed on 4 ft × 8 ft (1.22 m × 2.44 m) assemblies using 20 gauge steel studs. The assembly descriptions are summarized in Table 3. The test protocol is outlined in Table 4.

For the interpretation of static shear wall tests, it is typical to apply a safety factor of three to the ultimate load. Following the 1994 Northridge earthquake, it was recognized that the allowable shear wall values in the *Uniform Building Code* (UBC 1994) might not be conservative enough. One jurisdiction (the City of Los Angeles) has implemented a 25% reduction on these allowable values until it is shown that the current code values are applicable. Thus, conservatively, the allowable design values for seismic zones may be taken as the lesser of the ultimate load divided by a safety factor of 4 (corresponding to a safety factor of 3 and an additional 25% reduction) and the load at a displacement of 0.5% drift (0.48 in. [12.19 mm] for an 96 in. high shear wall). This interpretation is used to derive seismic design values for the shear wall assemblies tested in this study.

TABLE 1A
Series-Parallel Heat Flow Path Calculation through a 2-by-4 Wood-Framed Wall with Both Cavity and Rigid Strip Insulation[1]

Path 1: Through the Full-Height Cavity and Insulation		Path 2: Through Studs, Sills, Plates and Headers	
Outside Surface (15 mph wind)	0.17	0.17	(h·ft^2·°F)/Btu
Wood Bevel Lapped Siding	0.81	0.81	(h·ft^2·°F)/Btu
Building Paper 1 Layer	0.06	0.06	(h·ft^2·°F)/Btu
1/2 in. Plywood Sheathing	0.60	0.60	(h·ft^2·°F)/Btu
2×4 Wood Framing Member		4.375	(h·ft^2·°F)/Btu
2" of Extruded Polystyrene Rigid Insulation Strips	—	10	(h·ft^2·°F)/Btu
Cavity Insulation	17.6	—	(h·ft^2·°F)/Btu
0.5 in. Gypsum Board	0.45	0.45	(h·ft^2·°F)/Btu
Inside Surface (Still Air)	0.68	0.68	(h·ft^2·°F)/Btu
Total R-Value	20.37	17.145	(h·ft^2·°F)/Btu
U-Factor=1/R	0.04909	0.05833	(h·ft^2·°F)/Btu
Fraction of Area	75%	25%	—
U-Factor × Fraction of Area	0.036819	0.014582	—
Overall U-factor	**0.0514 (h·ft^2·°F)/Btu**		
Overall R-value	**19.46 (h·ft^2·°F)/Btu**		

[1] R-17.6 (h·°F·ft^2)/Btu cavity insulation with 2 in. extruded polystyrene rigid insulation strips on 1.5 in. by 3.5 in. wood studs, 25% framing factor based on 16 in. on-center stud spacing, sills, plates, doubles, and headers.

TABLE 1B
Series-Parallel Heat Flow Path Calculation through a 38.1 mm × 88.9 mm Wood-Framed Wall with Both Cavity and Rigid Strip Insulation[1]

Path 1: Through the Full-Height Cavity and Insulation		Through Studs, Sills, Plates and Headers	
Outside Surface (6.705 m/s wind)	0.030	0.030	$(m^2 \cdot K)/W$
Wood Bevel Lapped Siding	0.143	0.143	$(m^2 \cdot K)/W$
Building Paper 1 layer	0.011	0.011	$(m^2 \cdot K)/W$
12.7 mm Plywood Sheathering	0.106	0.106	$(m^2 \cdot K)/W$
38.1 mm × 88.9 mm Wood Framing Member	—	0.771	$(m^2 \cdot K)/W$
50.8 mm of Extruded Polystyrene	—	1.761	$(m^2 \cdot K)/W$
Rigid Insulation Strips			
Cavity Insulation	3.100	—	$(m^2 \cdot K)/W$
12.7 mm Gypsum Board	0.079	0.079	$(m^2 \cdot K)/W$
Inside Surface (Still Air)	0.120	0.120	$(m^2 \cdot K)/W$
Total R-Value	3.588	3.020	$(m^2 \cdot K)/W$
U-Factor = 1R	0.009	0.010	$(m^2 \cdot K)/W$
Fraction of Area	75%	25%	—
U-Factor × Fraction of Area	0.209	0.083	—
Overall U-Factor	**0.292 W/($m^2 \cdot K$)**		
Overall R-value	**3.427 W/($m^2 \cdot K$)**		

[1] 3.10 $(m^2 \cdot K)/W$ cavity insulation with 50.8 mm extruded polystyrene rigid insulation strips on 38.1 mm × 88.9 mm wood studs, 25% framing factor based on 406.4 mm on-center stud spacing, sills, plates, doubles, and headers.

TABLE 2A
Summary of Six Wood Frame Wall Assemblies Calculated Using the Series-Parallel Heat Flow Model[1]

Assembly	Wood Framing Member	Insulation Applied to Frame $(h \cdot ft^2 \cdot °F)/Btu$	Cavity Insulation	Opaque Wall R-Value[2] $(h \cdot ft^2 \cdot °F)/Btu$	Opaque Wall U-Value[2] $Btu/(h \cdot ft^2 \cdot °F)$
1	2 × 4	2.75 in. XPS R-13.5	19.0	21.5	0.0464
2	2 × 6	0.75 in. faced polyisocyanurate R-5.28	19.0	19.5	0.0512
3	2 × 4	2 in. extruded polystrene (XPS), R-10	17.6	19.5	0.0514
4	2 x 6	0.75 in. XPS, R-3.75	19.0	18.8	0.0531
5	2 x 6	—	17.6	15.9	0.0627
6	2 × 4	—	15.0	13.0	0.0772

[1] The fiberglass batt used in these calculations is rated at R-19 when fully uncompressed in a 6.25 in. cavity. When compressed into a 5.5 in. cavity, this same batt only achieves R-17.6 thermal resistance. Other assembly details are taken from Table 1a. 2×6 nominal wood member is actually 1.5 in. wide by 5.5 in. deep. Other assembly details are taken from Table 1.
[2] Opaque wall assembly R-values based on air-to-air resistances.

TABLE 2B
Summary of Six Wood Frame Wall Assemblies Calculated Using the Series-Parallel Heat Flow Model[1]

Assembly	Wood Framing Member	Insulation Applied to Frame W(m^2·K)	Cavity Insulation W(m^2·K)	Opaque Wall R-Value[2] W(m^2·K)	Opaque Wall U-Value[2] W(m^2·K)
1	38.1 mm × 88.9 mm	69.85 mm XPS R-2.38	3.46	3.79	0.264
2	38.1 mm × 152.4 mm	19.05 mm faced polyisocyanurate R-0.930	3.46	3.43	0.291
3	38.1 mm × 88.9 mm	508 mm extruded polystyrene (XPS), R-1.761	3.10	3.43	0.291
4	38.1 mm × 152.4 mm	19.05 mm XPS, R-0.660	3.46	3.31	0.302
5	38.1 mm × 152.4 mm	—	3.10	2.80	0.356
6	38.1 mm × 88.9 mm	—	2.64	2.29	0.437

[1] The fiberglass batt used in these calculations is rated at R-3.46 when fully uncompressed in a 158.75 mm cavity. When compressed into a 139.7 mm cavity, this same batt only achieves R-3.10 thermal resistance· Other assembly details are taken from Table 1b.
[2] Opaque wall assembly R-values based on air-to-air resistance.

The test results are summarized in Table 5. Adding foam inserts of relatively low compressive strengths (less than 100 psi [689.5 kPa] resistance to 10% compression) imparts ductility to the wall assembly in proportion to the thickness of insulator utilized. The test results illustrate that this ductility can be controlled by increasing the diameter of the fastener head or to the same effect by the addition of a washer. The ½ in. and 1 in. snap cap thickness tests utilizing washers (A1, A2, and A3) were stiffened so much so that the mode of failure was screw fracture. With the 2 in. snap caps and 2 in. washers (A6), the washer's stiffness was tempered by the added ductility (2 in. of unsupported fastener length) so that the mode of failure was pull-through in the sheathing rather than screw fracture. In the assemblies without washers, failure was initiated by deformation of the OSB around the screw head as the head pressed into the OSB and the screws tilted with respect to the plane of the stud flange. Greater ultimate capacities and larger deformations are seen when washers are not used. For assemblies with large ultimate displacements, buckling in the compression chord was the ultimate failure mode.

TABLE 3A
Shear Wall Assembly Descriptions[1]

Test \Specimen	Foam Insert	Assembly Description and Fastener Schedule
Pilot2	½ in. 25 psi	OSB: No. 8 screws at 4 in. /12 in. GWB: No. 6 screws at 6 in./12 in.
A7	½ in. 30 psi	OSB: No. 12 screws at 6 in./12 in. one side of the assembly left open
A9	½ in. 30 psi	OSB: No. 12 screws at 3 in./12 in. one side of the assembly left open
A1 and A2	½ in. 100 psi	Plywood: No. 12 screws at 3 in./12 in.; 2 in. washers used with screws; GWB; No. 6 screws at 6 in./12 in.
A3	1 in. 100 psi	Plywood: No. 12 screws at 3 in./12 in.; 2 in. washers used with screws; GWB; No. 6 screws at 6 in./12 in.
A4	1 in. 100 psi	Plywood: No. 12 screws at 3 in./12 in. GWB: No. 6 screws at 6 in./12 in.
A5	1 in. 30 psi	Plywood: No. 14 screws at 3 in./12 in. GWB No. 6 screws at 6 in./12 in.
Pilot1	2 in. 25 psi	OSB: No. 8 Screws at 4 in./ 12 in. GWB No. 6 screws at 12 in./12 in.
A6	2 in. 100 psi	Plywood; No. 12 screws at 3 in./12 in. GWB: No. 6 screws at 12 in./ 12 in.

[1] All walls framed with 20 gauge studs and tracks. 15/32 in. APA rated plywood sheathing and 7/16 in. APA rated OSB sheathing are denoted in the descriptions as "plywood" and "OSB," respectively; ½ in. gypsum wallboard is denoted as "GWB" in the descriptions.Cap track installed over chord stud for increased capacity in compression.The rigid foam insert is extruded polystyrene foam material in all cases.These are compressive resistance minimums listed by the manufacturers for the extruded polystyrene materials used in this program.

TABLE 3B
Shear Wall Assembly Descriptions[1]

Test \ Specimen	Foam Insert	Assembly Description and Fastener Schedule
Pilot2	12.7 mm 172 kPa	OSB: No. 8 screws at 101.6 mm/304.8 mm GWB: No 6 screws at 152.4 mm/304.8 mm
A7	12.7 mm 207 kPa	OSB: No. 12 screws at 152.4 mm/304.8 mm One side of assembly left open
A9	12.7 mm 207 kPa	OSB: No. 12 screws at 76.2 mm/304.8 mm One side of the assembly left open
A1 and A2	12.7 mm 690 kPa	Plywood: No. 12 screws at 76.2 mm/304.8 mm 50.8 mm washers used with screws; GWB: No. 6 screws at 152.4 mm/304.8 mm
A3	25.4 mm 690 kPa	Plywood: No. 12 screws at 76.2 mm/304.8 mm, 50.8 mm washers used with screws GWB; No. 6 screws at 152.4 mm/304.8 mm
A4	25.4 mm 690 kPa	Plywood: No. 12 screws at 76.2 mm/304.8 mm GWB: No. 6 screws at 152.4 mm/304.8 mm
A5	25.4 mm 207 kPa	Plywood: No. 14 screws at 76.2 mm/ 304.8 mm GWB: No. 6 screws at 152.4 mm/304.8 mm
Pilot1	50.8 mm 172kPa	OSB: No. 8 screws at 101.6 mm/304.8 mm GWB: No. 6 screws at 304.8 mm/304.8 mm
A6	50.8 mm 690 kPa	Plywood: No. 12 screws at 76.2 mm/304.8 mm GWB: No. 6 screws at 152.4 mm/304.8 mm

[1] All walls framed with 20 gauge studs and tracks. 11.9 mm APA rated plywood sheathing and 11.1 mm APA rated OSB sheathing are denoted in the descriptions as "plywood" and "OSB," respectively; 12.7 mm gypsum wallboard is denoted as "GWB" in the descriptions. Cap track installed over chord stud for increased capacity in compression. The rigid foam insert is extruded polystyrene foam material in all cases. These are compressive resistance minimums listed by the manufacturers for the extruded polystyrene materials used in this program

TABLE 4
Test Protocol

Load Step	Description
1	Monotonically load wall to 0.5 in. (12.7 mm) (total top of wall lateral displacement)
2	Unload the assembly to zero load
3	Reload monotonically to 1.5-in. (38.1 mm) (total top of wall lateral displacement)
4	Unload the assembly to zero load
5	Reload monotonically to failure (10% drop in load for increasing lateral displacement)

For the range of insulators tested (25 psi [172.4 kPa], 30 psi [206.9 kPa], and 100 psi [689.5 kPa]),[2] the compressive resistance of the insulator had a much smaller impact on the assembly load transfer paths than the shank and head diameters of the fastener. Indeed, the fastener shank diameter had a greater impact than any other component. This is illustrated by comparing the A3, A4, and A5 test results. The two pilot tests (Pilot1 and Pilot2) make use of standard number 8 framing screws; these lower strength results can be used to support exterior wall design for low shear applications. In all of the assemblies with gypsum wallboard, the gypsum wallboard failed at a relatively low lateral displacement of approximately 0.6 in. (15.2 mm) displacement and had no impact on the ultimate loads.

For comparison purposes, several conventional shear walls of comparable construction that were tested in a previous study (Serrette and Ngyen 1996) are listed in Table 6. These comparison walls use number 8 screws for the structural sheathing attachment. The results of the study show that by using fasteners with larger wire diameters, such as number 12 or number 14, for the sheathing attachment at the same fastening schedule, shear walls of comparable strength can be obtained. The larger wire diameter compensates for the unsupported length of the connector through the rigid insulator. Indeed, at tight fastening schedules such as 3/12 (76.2 mm/304.8 mm), the insulated systems with larger fasteners are likely to yield higher ultimate loads that the uninsulated assemblies that use number 8 fasteners.

[2] Compressive strengths are minimum resistance values to 10% deflection (ASTM D1621) published by the manufacturers for the extruded polystyrene materials used in this program.

TABLE 5A
Assembly Ultimate Loads, Displacements, and Calculated Design Loads

Test Specimen (Thickness of Insulating Foam, in.)	Ultimate Load Capacity, lb/ft	Displacement at Ultimate Load, in.	Load Capacity at 0.5 in. Displacement, lb/ft	Load Capacity at 1.5 in. Displacement, lb/ft	Seismic Design Load[1] lb/ft	Wind Design Load[2] lb/ft
Pilot2 (0.5 in.)[3]	721	1.80	456	691	180	240
A7 (0.5 in.)	883	2.92	320	600	221	294
A9 (0.5 in.)	1863	>4.00[4]	480	890	466	480[5]
A1 (0.5 in.)	1488	2.36	690	1112	372	496
A2 (0.5 in.)	1349	2.28	690	1244	337	450
A3 (1 in.)	1275	2.45	663	1031	319	425
A4 (1 in.)	1322	> 3.50 [4]	603	872	331	441
A5 (1 in.)	1799	>3.25[4]	640	1069	445	593
Pilot1 (2 in.)	507[6]	2.94[6]	243	374	127	169
A6 (2 in.)[7]	1506	4.25[4]	760	1092	377	502

1 Seismic design load equals the lesser of the load at ½ in. displacement and ultimate load divided by 4 (see text for description).
2 Wind design load equals the lesser of the load at 0.5 in. displacement and the ultimate load divided by a safety factor of 3.
3 Pilot2 was loaded and unloaded at 0.5 in., 1 in., 1.5 in., and then to failure.
4 The displacement measurement device was removed at the indicated displacement prior to ultimate load.
5 The calculated design load of 621 lb/ft is greater than the 480 lb/ft value at 0.5 in. displacement, so the value at 0.5 in. should be used.
6 Pilot1 was the first assembly to be tested and was not loaded to failure. The value listed occurred at 2.94 in. of displacement.
7 Cap track installed over chord stud for increased capacity in compression.

TABLE 5B
Assembly Ultimate Loads, Displacements, and Calculated Design Loads

Test Specimen (Thickness of Insulating Foam, in.)	Ultimate Load Capacity, (kg/m)	Displacement at Ultimate Load, mm	Load Capacity at 12.7 mm in Displacement, (kg/m)	Load Capacity at 1.5 in. Displacement, (kg/m)	Seismic Design Load[1] lb/ft (kg/m)	Wind Design Load[2] lb/ft (kg/m)
Pilot2 (0.5 in.)[3]	1074	45.72	456	679	268	358
A7 (0.5 in.)	1316	74.17	320	477	329	438
A9 (0.5 in.)	2776	>101.60[4]	480	715	694	715[5]
A1 (0.5 in.)	2217	59.94	690	1028	554	739
A2 (0.5 in.)	2010	57.91	690	1028	502	671
A3 (1 in.)	1900	62.23	663	988	475	633
A4 (1 in.)	1970	>88.90 [4]	603	898	493	657
A5 (1 in.)	2651	82.55[4]	640	954	663	884
Pilot1 (2 in.)	755[6]	74.68[6]	243	362	189	252
A6 (2 in.)[7]	2244	≥107.95[4]	760	1132	562	748

1 Seismic design load equals the lesser of the load at 12.7 mm displacement and ultimate load divided by 4 (see text for description).
2 Wind design load equals the lesser of the load at 12.7 mm displacement and the ultimate load divided by a safety factor of 3.
3 Pilot2 was loaded and unloaded at 12.7 mm, 25.4 mm, 38.1 mm, and then to failure.
4 The displacement measurement device was removed at the indicated displacement prior to ultimate load.
5 The calculated design load of 621 lb/ft is greater than the 715 kg/m value at 12.7 mm displacement, so the value at 12.7 mm should be used.
6 Pilot1 was the first assembly to be tested and was not loaded to failure. The value listed occurred at 74.7 mm of displacement.
7 Cap track installed over chord stud for increased capacity in compression.

TABLE 6A
Standard Shear Wall Test Results Excerpted for Comparison From Static Test [Serrette and Ngyen 1996][1]

Ref No.	Sheathing Thickness and Type	Screw Spacing Edge/Field	Ultimate Shear (lb/ft)
1F1, 1F2	7/16 in. OSB	6/12	910
1A2, 1A3	7/16 in.	3/12	1735
1F3, 1F4	7/16 in. OSB and ½ in. GWB	4/12 7/7	1560

[1] The sheathing orientation is vertical. The screw size for plywood and OSB was number 8. Screws for GWB were number 6.

TABLE 6B
Standard Shear Wall Test Results Excerpted for Comparison From Static Test [Serrette and Ngyen 1996][1]

Ref No.	Sheathing Thickness and Type	Screw Spacing Edge/Field (mm)	Ultimate Shear (kg/m)
1F1, 1F2	11.1 mm OSB	152.4 mm/304.8 mm	1356
1A2, 1A3	11.1 mm OSB	76.2 mm/304.8 mm	2585
1F3, 1F4	11.1 mm OSB and 12.7 mm GWB	101.6 mm/304.8 mm 177.8 mm/177.8 mm	2324

[1] The sheathing orientation is vertical. The screw size for plywood and OSB were number 8. Screws for GWB were number 6.

CONCLUSIONS

The thermal resistance of the opaque building assembly can be greatly enhanced by insulating the frame in addition to the cavities. This technique is beneficial for both wood and steel framing techniques. Indeed, this approach would improve the thermal performance of the building assembly regardless of the framing material. Rigid insulation can be extremely effective when applied in less than full-sheet techniques. This affords the designer a high degree of flexibility in balancing the budgetary, environmental, and thermal performance objectives of a project. This system employs an optimal insulation placement strategy to reduce the economic cost per square foot for a given wall resistance to heat flow. Several product embodiments that are beyond the scope of this paper were developed to reduce the installation labor below that of conventional sheets of rigid insulation. These embodiments include a friction-fit cap design to fit the framing members and "peel-and-stick" adhesive-backed components. Building codes should neither oversimplify nor hide the problem of thermal bridging. By doing so, the codes fail to educate building practitioners, owners, and occupants about the problem. The basic question regarding shear wall construction was how does the rigid foam impact the lateral resistance of the sheathed wall to wind and seismic loads? Based on these preliminary tests, it appears that adequate shear strength can be developed for use in shear wall assemblies to resist high wind and seismic loads. By increasing the fastener size on shear wall assemblies employing rigid insulation between the shear panel and the structural frame, comparable lateral resistance strengths can be achieved at equivalent fastening schedules to conventional shear wall assemblies. For regions with lower wind and seismic requirements, standard fastener sizes and schedules may be appropriate.

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