

research report

Development of Cost-Effective, Energy Efficient Steel Framing: Thermal Performance of Slit-Web Steel Wall Studs

RESEARCH REPORT RP02-9

2002

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American Iron and Steel Institute



Steel Framing Alliance™

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PREFACE

This report presents the results of thermal studies that were performed at the NAHB Research Center and testing that was conducted at the Oak Ridge National Laboratory on prototype slit web studs. Thermal test results showed that the prototype slit web studs performed 17 percent better than the solid-web studs.

As an extension of this project in 2003, the NAHB Research Center was retained to develop maps to show where the 3.5" and 5.5" thermal studs would meet model energy code requirements with various thickness exterior insulation sheathing and to define residential market size described by each zone of the maps. The 2003 ICC International Energy Conservation Code was used to identify the energy and insulation levels (i.e., effective wall R-value) for each zone, assuming R13 cavity insulation in 3.5" walls, R19 cavity insulation in 5.5" walls and 15 percent glazing with a U-factor of 0.45. The NAHB Research Center Builders' Practice Survey and a Steel Framing Alliance market analysis was used to define the market potential for each zone of the thermal zone map. The maps for a 3.5" solid-web stud, 5.5" solid-web stud, 3.5" slit-web stud and 5.5" slit web stud are shown on the following pages. From this data, the table below provides the percentage of U.S. housing starts that would comply with the model energy code using each of the methods.

**Compliance with Model Energy Code
Percentage of U.S. Housing Starts**

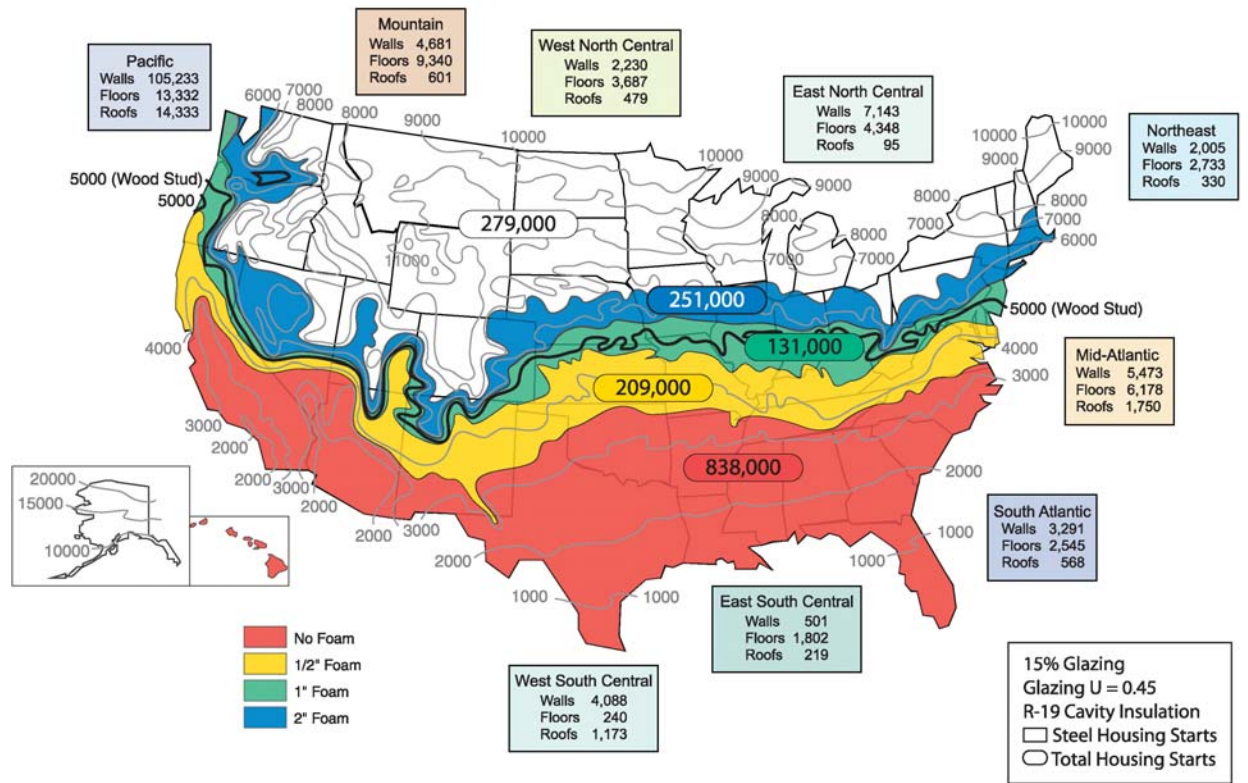
	No Sheathing	½" Sheathing	1" Sheathing	2" Sheathing
3.5" Wood	65%	76%	83%	100%
5.5" Wood	83%	92%	100%	100%
3.5" Solid	49%	61%	69%	84%
5.5" Solid	59%	69%	83%	100%
3.5" Slit	54%	71%	78%	100%
5.5" Slit	65%	73%	100%	100%

This market evaluation concluded that about 2/3 of the houses in the U.S. could be built with 2x4 wood studs and no exterior foam insulation and still meet the model energy code. Switching to 2x6 wood studs increases this share to 83 percent; however, exterior foam insulation is needed in significant portions of the U.S. with wood framing. On the other hand, only about half of the houses in the U.S. could be built with 2x4 steel studs and no exterior foam insulation. Switching to 2x6 steel studs increases this share, but only to 59 percent. Using a slit web stud increases these shares and reduces the amount of exterior foam insulation needed.

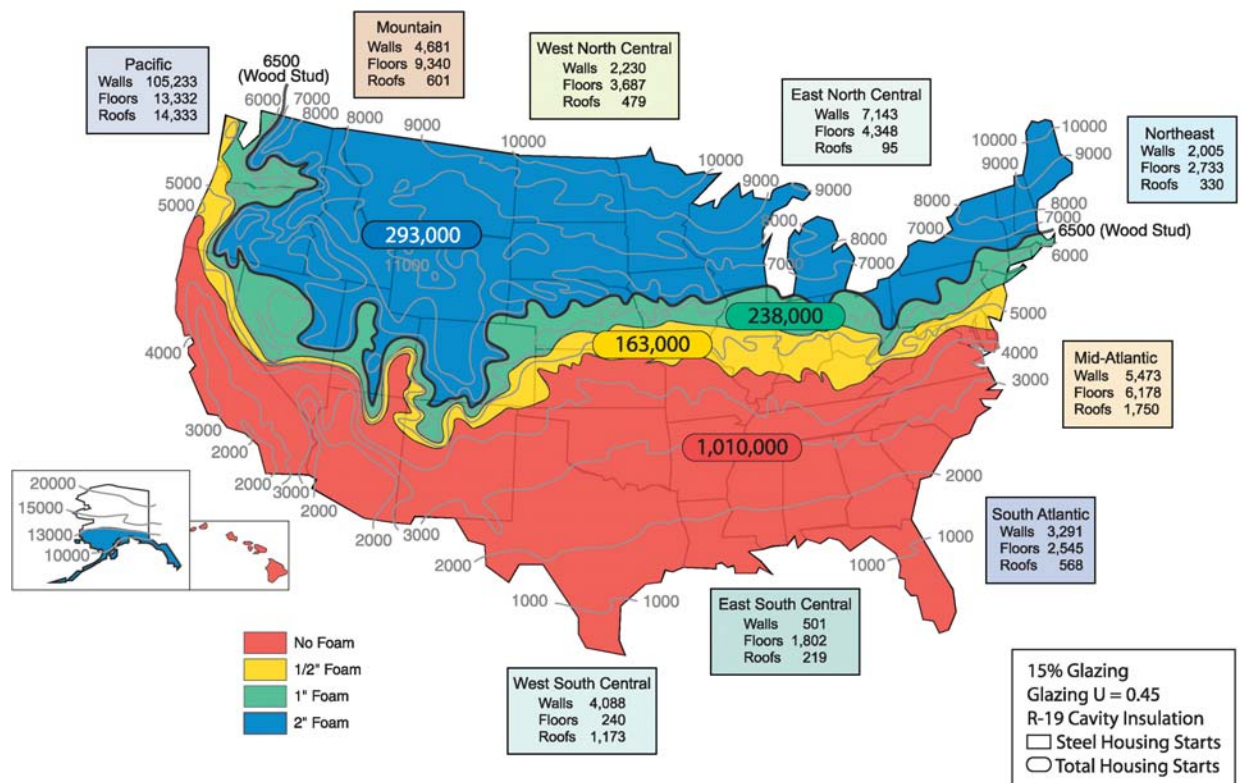
Based on this work, and that of the companion report on Structural Performance of Slit-Web Steel Wall Studs, it is hoped that manufacturers may have interest in commercializing the thermal stud.

Research Team
Steel Framing Alliance

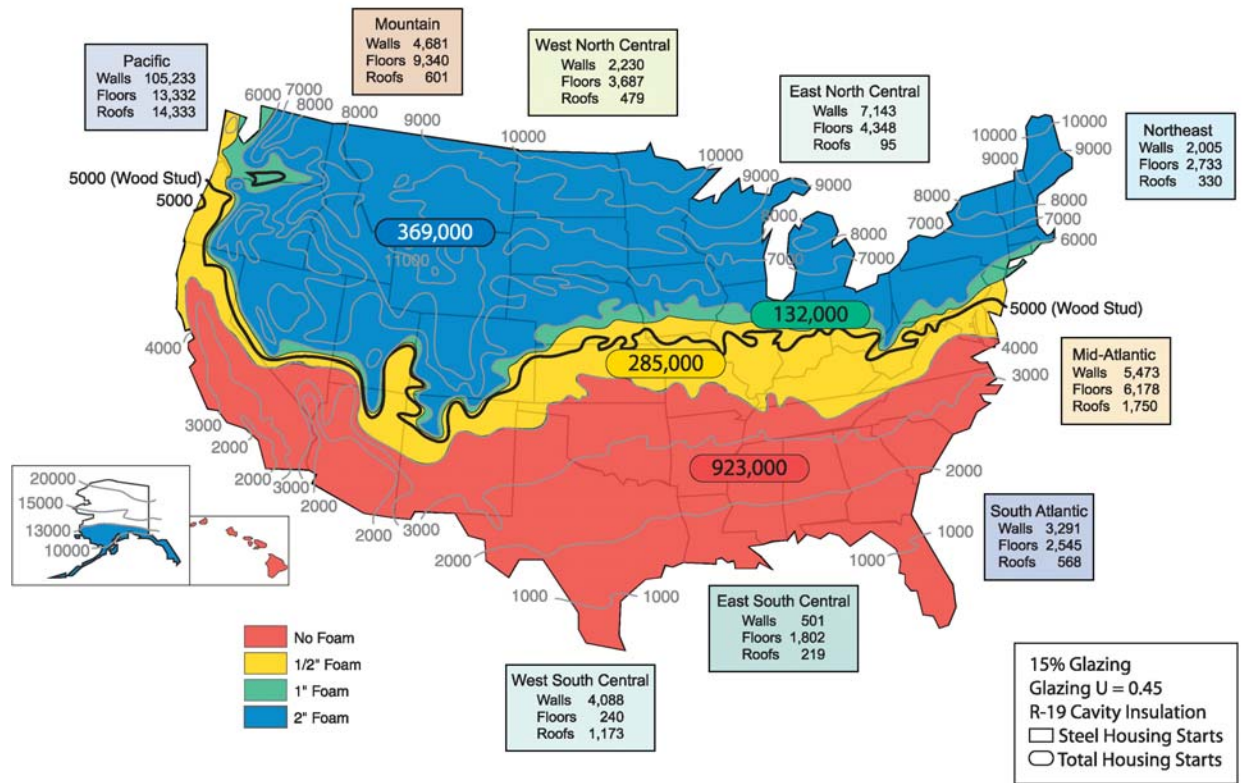
3.5" Solid Web Stud



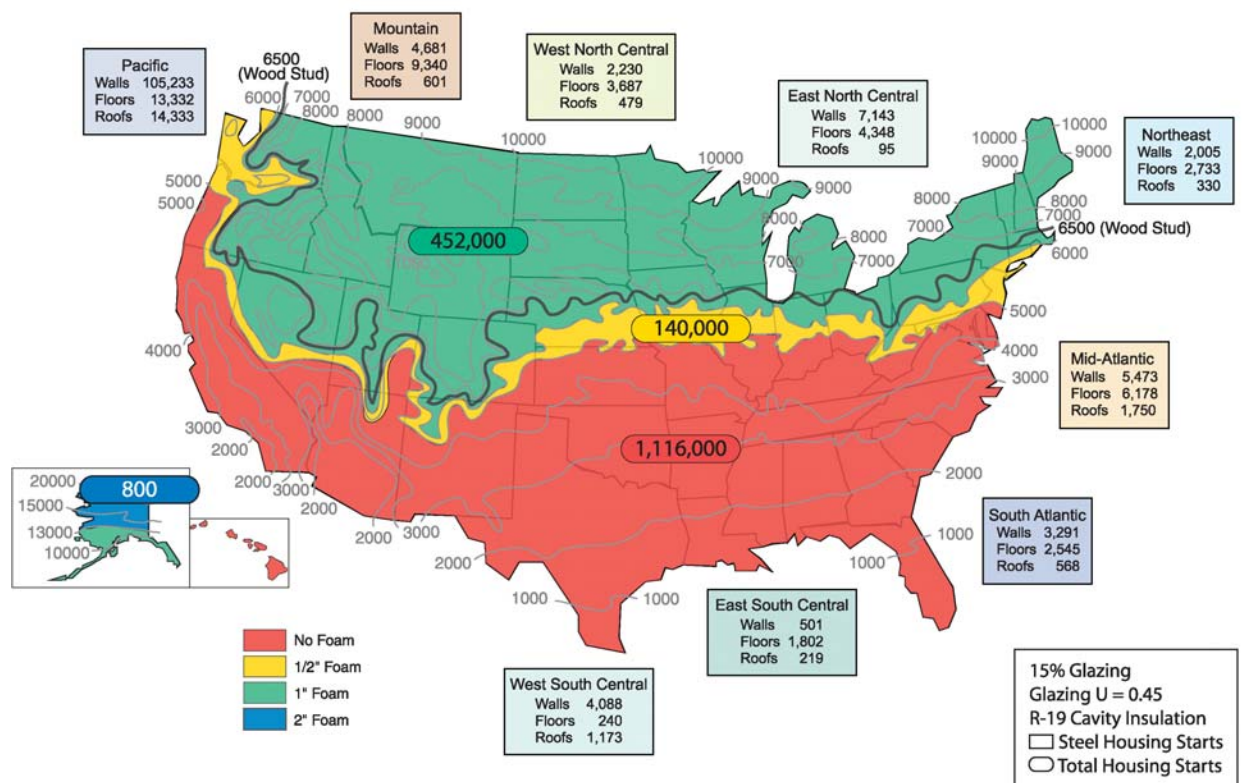
5.5" Solid Web Stud



3.5" Slit Web Stud



5.5" Slit Web Stud



Development of Cost-Effective, Energy -Efficient Steel Framing

Thermal Performance of Slit-Web Steel Wall Studs

Prepared for

American Iron and Steel Institute
Washington, DC

And

Steel Framing Alliance
Washington, DC

And

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Thermal Performance of Slit-Web Steel Wall Studs



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Thermal Performance of Slit-Web Steel Wall Studs



EXECUTIVE SUMMARY

Steel members in wall construction form a thermal bridge that interrupts the insulation layer of a wall. This causes higher rate of heat transfer by conduction through the wall framing than through other parts of the wall. One method to reduce the thermal bridging effect is to provide a break, such as insulating sheathing. A thermally efficient slit-web stud was developed in this program to mitigate the conductivity of steel. The prototype slit-web steel stud has been shown to be:

- Thermally efficient
- Economically viable
- Structurally sound
- Easily manufactured
- Usable in a range of residential installations (“Buildable”)

The performance of the slit-web stud was confirmed by thermal testing. Hot-box (thermal) testing was conducted at Oak Ridge National Laboratory. Thermal test results showed that the prototype slit web studs performed 17 percent better than the solid-web studs, giving an overall wall resitivity of R-10.4 for the slit-web 350S162-33 stud wall using R-13 fiberglass batts with exterior OSB sheathing and ½” interior drywall compared to an R-8.9 for solid web studs with the same configuration. Test results also proved that the best performing walls are those using slit web studs and angles (for top tracks), yielding a wall R-value of 11.4. Adding a thin layer of polyisocyanurate foam insulation on the exterior increases the wall R-value to 14.1; i.e., 28 percent improvement over solid web studs.

Thermal Performance of Slit-Web Steel Wall Studs



ABSTRACT

Thermal solution options for cold-formed steel wall framing were reviewed and evaluated. The most promising solutions were further investigated and a thermally efficient stud was developed in this program to mitigate the conductivity of steel. The thermal performance of 3-1/2 inch (89 mm) slit-web stud (perforated web) was evaluated by performing hot-box tests at Oak Ridge national Lab. Thermal test results showed that the prototype slit web studs performed 17 percent better than the solid-web studs, giving an overall wall resisitivity of R-10.4 for the slit-web 350S162-33 stud wall using R-13 fiberglass batts with exterior OSB sheathing and 1/2" interior drywall compared to an R-8.9 for solid web studs with the same configuration. Test results also proved that the best performing walls are those using slit web studs and angles (for top tracks), yielding a wall R-value of 11.4. Adding a thin layer of polyisocyanurate foam insulation on the exterior increases the wall R-value to 14.1; i.e., 28 percent improvement over solid web studs.

Thermal Performance of Slit-Web Steel Wall Studs



INTRODUCTION

Cold-formed steel framing has seen some market growth in the housing market. However, due to concerns about the thermal performance of steel, the use of steel framing in the residential market is still low.

Steel members in wall construction form a thermal bridge that interrupts the insulation layer of a wall. This causes higher rate of heat transfer by conduction through the wall framing than through other parts of the wall. One method to reduce the thermal bridging effect is to provide a break, such as insulating sheathing. Recommended sheathing thicknesses for various steel wall sizes are given in the Thermal Design Guide [1]. The exterior insulation thickness can be as high as 2 inches to achieve a required (effective) R-value. This can be costly and inefficient. Thick exterior insulation typically requires longer (expensive and hard to find) screws and creates a challenge for siding installation.

Most builders currently use one or more of the following construction methods to create a thermally efficient steel stud wall system:

- Increasing the fiberglass batt insulation in the wall cavity (such as R-15 instead of the typical R-11).
- Increasing the spacing between the steel studs to 24 inches on center instead of the typical 16 inches on center (for wood studs).
- Adding exterior insulating sheathing (such as rigid foam).
- Using larger studs (such as 5-1/2" instead of the 3-1/2") spaced further apart so that more cavity insulation can be used.
- Adding thicker rigid foam insulation on the exterior without any cavity insulation.

Studies suggest that some of the options listed above may not be adequate to overcome the thermal bridging that steel creates in a framed wall [2]. Therefore, it is essential that builders use the appropriate insulation material and thickness or provide an adequate thermal break to effectively reduce the thermal bridging effect.

PURPOSE

The objective of this program is to improve the building envelope thermal performance in cold-formed steel-framed homes, by developing and analyzing new "thermally efficient steel stud. The performance of the promising stud was confirmed by thermal testing to determine acceptable solutions for residential and light commercial construction. A list of existing wall systems and/or components (options) that potentially reduce house energy use (specially for steel-framed buildings) was compiled. The options were then evaluated based on whether the wall systems and components are:

- Thermally efficient
- Economically viable
- Structurally sound
- Easily manufactured
- Usable in a range of residential installations ("Buildable")

This evaluation has been conducted on dozens of types of wall systems that use such components as thermal breaks, modified studs, novel materials and new construction techniques. On a reduced set of promising technologies, this evaluation has been conducted quantitatively, using thermal finite element analysis and other techniques, as well as qualitatively.

Thermal Performance of Slit-Web Steel Wall Studs



This program was conducted in several stages as follows:

- **Review of Existing Solutions**

Measures, systems, or materials were investigated and reviewed which may be used to improve the thermal performance of the conventional and non-conventional cold-formed steel framed wall assemblies, considering different regions (e.g. hot and hot & humid, cold climate, and transitional climate). The information obtained was analyzed and evaluated.

- **Evaluation of Existing Solutions**

The systems and materials reviewed were then analyzed and evaluated to determine the best option. The selected configurations were evaluated using two-dimensional finite element analysis models to determine if the modeled performance warrants additional testing. In addition, constructability analysis was conducted to insure that the wall system could be manufactured and built prior to subjecting assemblies to testing.

- **Selection of Wall Configurations**

An option was chosen from the results of the previous stages. The selected configuration was further evaluated using two-dimensional finite element analysis to determine if the modeled performance warrants additional testing. A total of 10 wall assemblies were selected for thermal testing.

- **Thermal Testing of Wall Assemblies – Phase I**

Wall assembly tests, consisting of 8 foot by 8-foot wall samples, were executed in accordance with ASTM C1363 [3] with a hot side temperature of 70 °F and a cold side of 20 °F.

- **Thermal Testing of Wall Assemblies – Phase II**

Thermal test results from Phase I tests were reviewed. Modifications were made and the final “thermally efficient” stud wall system was developed. Additionally, 12 wall assembly tests, consisting of 8 foot by 8-foot wall samples, were executed in accordance with ASTM C1363.

- **Structural Testing of Walls**

Structural tests were conducted to assess the strength and stability of the recommended “thermally efficient” steel stud wall. The description and results of such tests are summarized in a separate report [4].

Thermal Performance of Slit-Web Steel Wall Studs



LITERATURE REVIEW

Researchers through out the world have investigated several techniques and proposed many ideas that mitigate the thermal concern of steel framing. Most of the methods and materials investigated were concentrated on increasing the thermal effectiveness of steel framed walls through:

- Reducing the contact area between the studs and the exterior sheathing materials,
- Reducing the steel stud web area,
- Placing foam insulation in locations where the thermal shorts are most critical, and,
- Modifying the stud web

Numerous papers, research reports and publications have been written about the thermal performance of cold-formed steel framing. Most of the reports and papers written address the negative performance of steel in cold climates. Table 1 lists a summary of the thermal options selected for review and evaluation in this report. The options in Table 1 are by no means inclusive. Figure 1 provides illustrations of some of the thermal options selected for review.

Researchers Bombino and Burnett concluded that a mere replacement of wooden studs with steel studs in a conventional wall assembly could result in halving the contribution of the insulation shown in Figure 2 [5]. Bombino and Burnett estimated the thermal efficiency of the steel-framed wall to be 55% compared to 89% for the wood-framed wall (taking into account the thermal effect of the studs). They further concluded that increasing the cavity batt insulation without adding exterior insulation produces nominal increase in the wall R-value but actually lowers the thermal efficiency of the wall from 55% to 51% (refer to Figure 3). Increasing the cavity insulation from R-11 to R-15 (a nominal increase of R-4) increases the average wall R-value by 1.1 and decreases the thermal efficiency of the wall to 47%. Bombino and Burnett also reported “the best strategy is a combination of cavity insulation and exterior sheathing.” This is illustrated in Figure 4 and 5.

Thermal Performance of Slit-Web Steel Wall Studs



Table 1 – List of Thermal Options

Option No.	Description	Option No.	Description
1	Snap-Cap™ (2")	34	Struct. Insul (CBS) w/ Slot Web & 26
2	Astec Ceramic Ins. Coating	35	Struct. Insul (Celotex Thermax) w/ Slot Web
3	Double Wall Metal Track	36	Struct. Insul (E'NRG'Y 2 Nailboard)
4	Double Wall Insulated Track	37	Thermal Tape
5	Slotted Web (Delta™)	38	SuperTherm Insulating Coating
6	Rigid Sheathing (1") Polystyrene	39	Metal/Foam Laminate Sheathing
7	Rigid Sheathing (2")	40	Foil-Backed Wallboard
8	Rigid Sheathing (2") with lathe/glue	41	Offset Framing
9	Rigid Sheathing (2") without plywood	42	Broken Web
10	Rigid Sheathing (1") Isocyanurate	43	Hybrid Stud
11	Ridged Flange	44	Panelized Walls (Thermastructure)
12	Studs with Dimpled Flange	45	Panelized Wall w/ ExcelBoard less Plywood
13	Circular Slot Web Stud	46	Foamed Cement/Metal Framing
14	Circ. Slot Web Stud w/ Sprayed Foam	47	PVC Clip
15	Circ. Slot Web Stud w/ Ridge & Foam	48	PVC Clip w/ Spray-in Foam
16	Circ. Slot Web Stud w/ Interior Foam/Z	49	PVC Clip w/ Spray-in Cellulose
17	Circ. Slot Web Stud w/ Ridge & Cellulose	50	PVC Clip w/ Oversized Foil-Faced Batt
18	Circ. Slot Web Stud w/ Thermal Tape	51	Insulated Drywall
19	Circ. Slot Web Stud w/ Foil-backed Wallboard	52	Insulated Drywall w/ Slotted Web
20	Circ. Slot Web Stud w/ Foil-Faced Insulation	53	Spray-in Foam
21	Circ. Slot Web Stud w/ Therm Tape & Foil Insul	54	ExcelBoard Structural Insulation
22	Furring Strips	55	Diversitec Structural Insulation
23	Furring Strips w/ foil-backed ins.	56	Fiberglass Batt w/ Foil over Flange
24	Furring Strips w/ Urethane Foam	57	Fiberglass Batt w/ Foil over Slotted Web
25	Furring Strips w/ Spray-in Cellulose	58	Gentec Insulated Siding
26	Furring Strips w/ Cellulose & Slotted Stud	59	AmazingWall Insulated Siding
27	Furring Strips w/ Foam & Slotted Stud	60	TechWall Insulated Siding
28	Furring Strips w/ EESI-Stud	61	TechWall Ins. Siding w/ Batt over Flange
29	EESI-Stud (Tri-Chord™)	62	TechWall Ins. Siding w/ Slotted Web
30	EESI-Stud w/ Thermal Tape	63	TechWall Siding w/ Batt & Slotted Web
31	Struct. Insul - Cellulosic Hardboard	64	Interior Rigid Foam w/ Z Strip
32	Struct. Insul - CBS Sheathing (1")	65	Interior Rigid Foam w/ Hat Channel
33	Struct. Insul (CBS) w/ Slotted Web	66	Inter. Rigid Foam w/ Z & Foil-Faced Insul

Thermal Performance of Slit-Web Steel Wall Studs

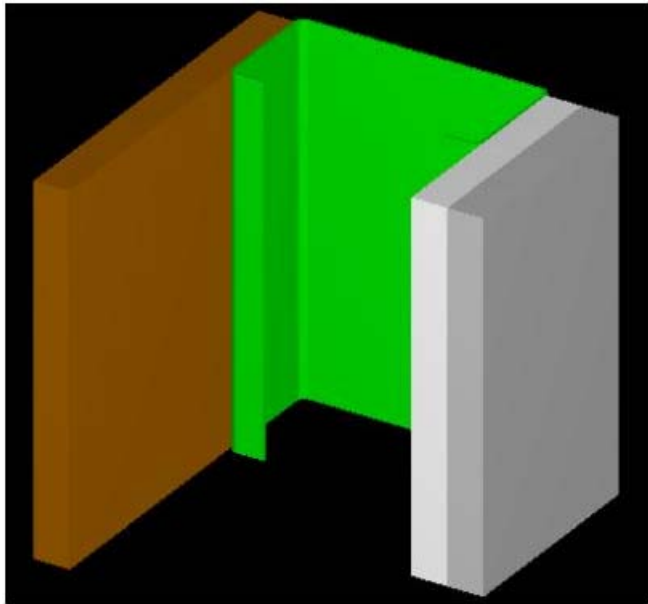
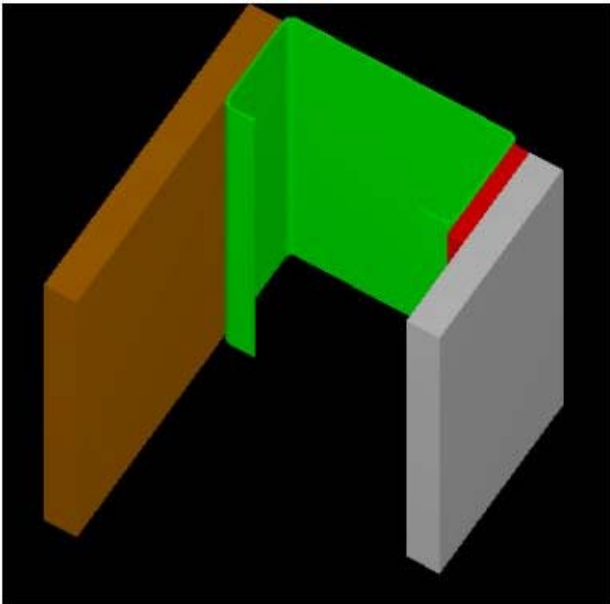
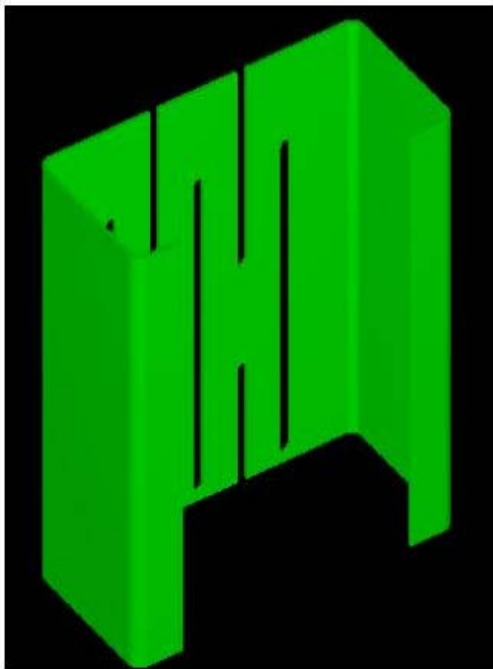
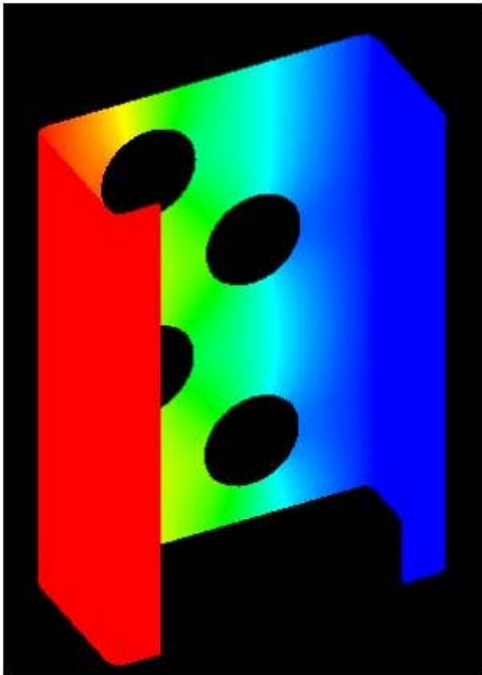


Figure 1 – Selected Thermal Options

Thermal Performance of Slit-Web Steel Wall Studs

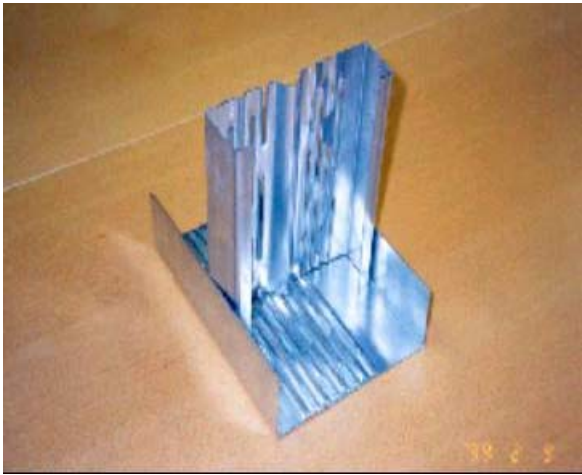
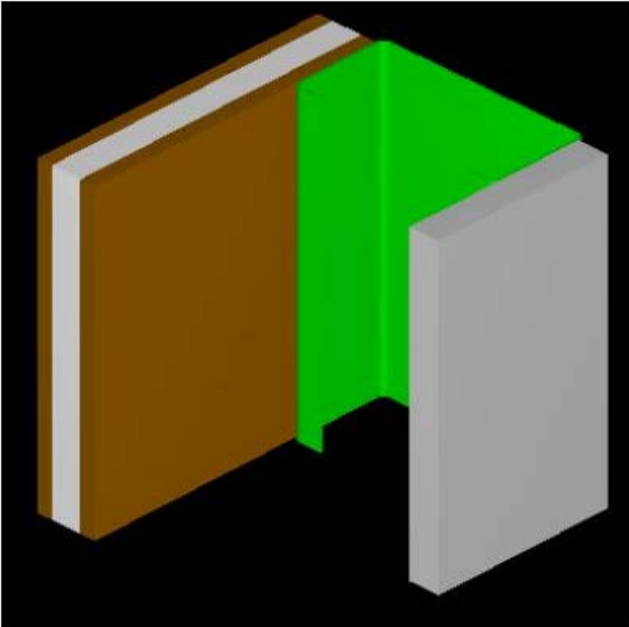


Figure 1 – Selected Thermal Options (cont.)

Thermal Performance of Slit-Web Steel Wall Studs

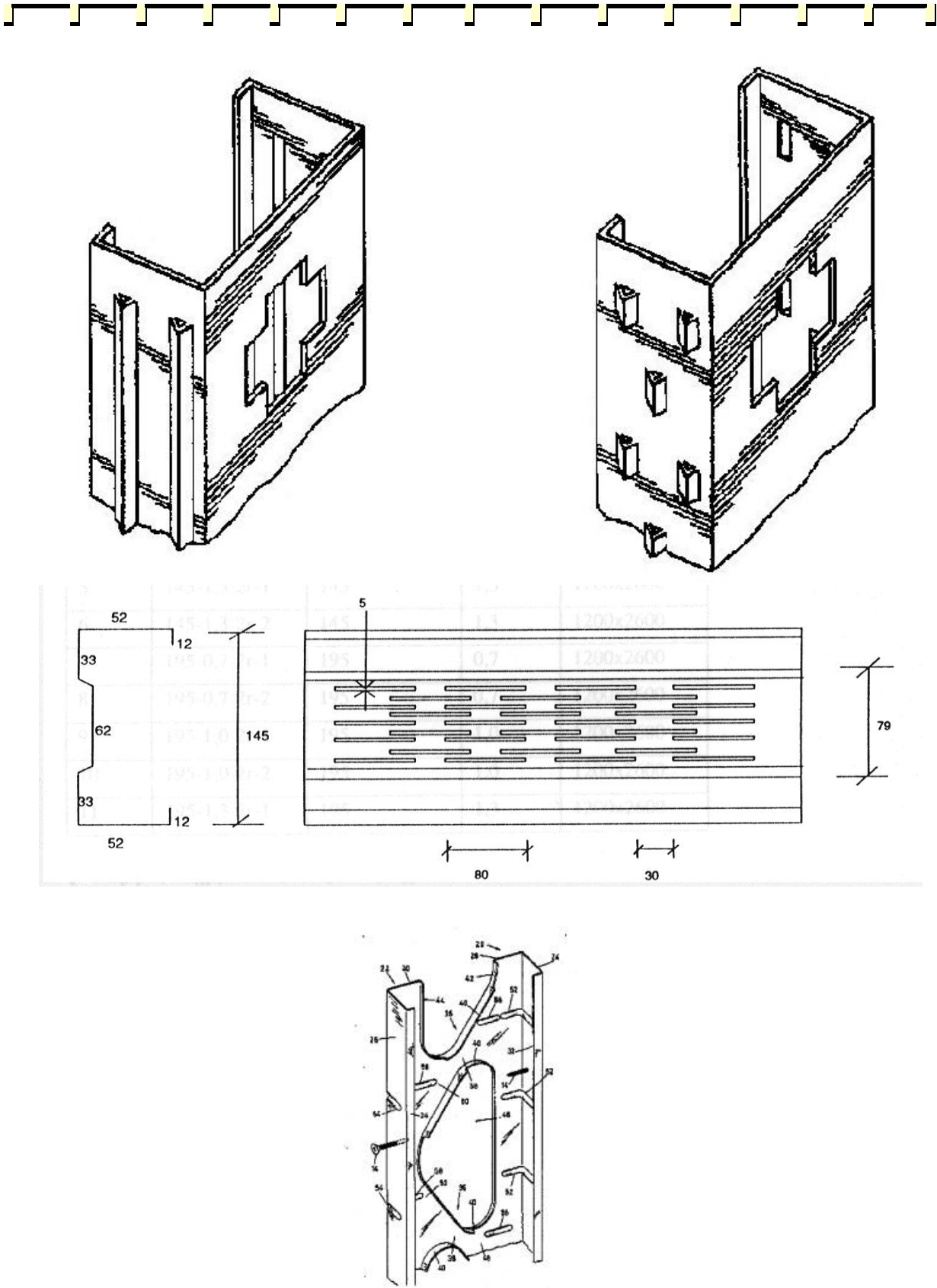


Figure 1 – Selected Thermal Options (cont.)

Thermal Performance of Slit-Web Steel Wall Studs

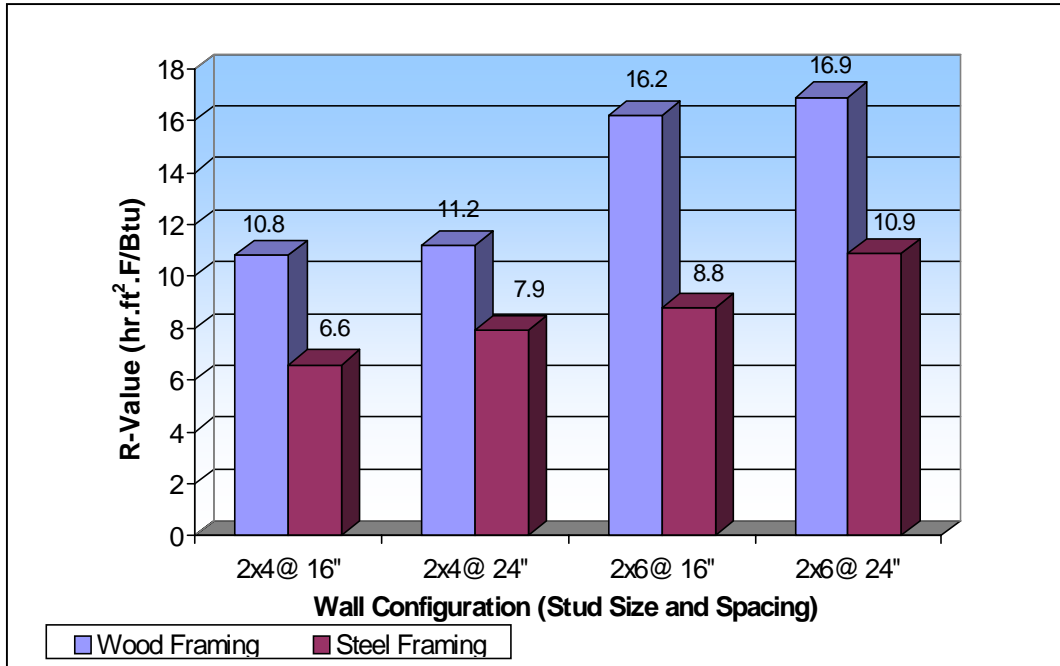


Figure 2 – Average R-Value for Various Wood- and Steel-Framed Walls
(Based on mere replacement of wooden studs with steel studs)

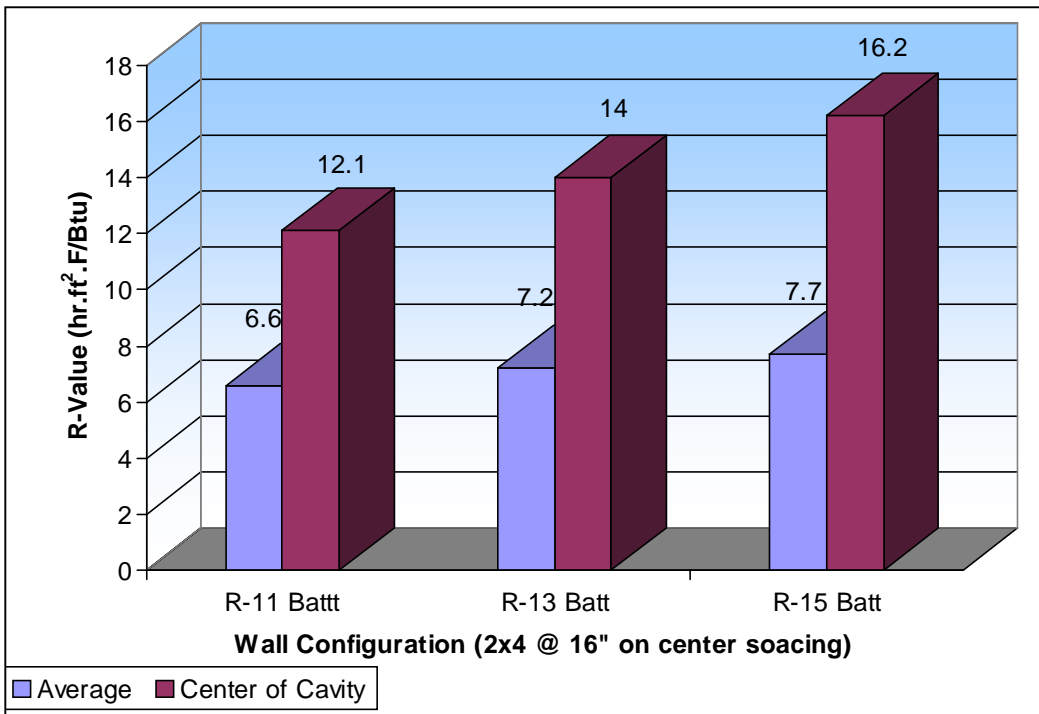


Figure 3 – Average Wall R-Value for Steel-Framed Walls with Different Levels of Cavity Insulation

Thermal Performance of Slit-Web Steel Wall Studs

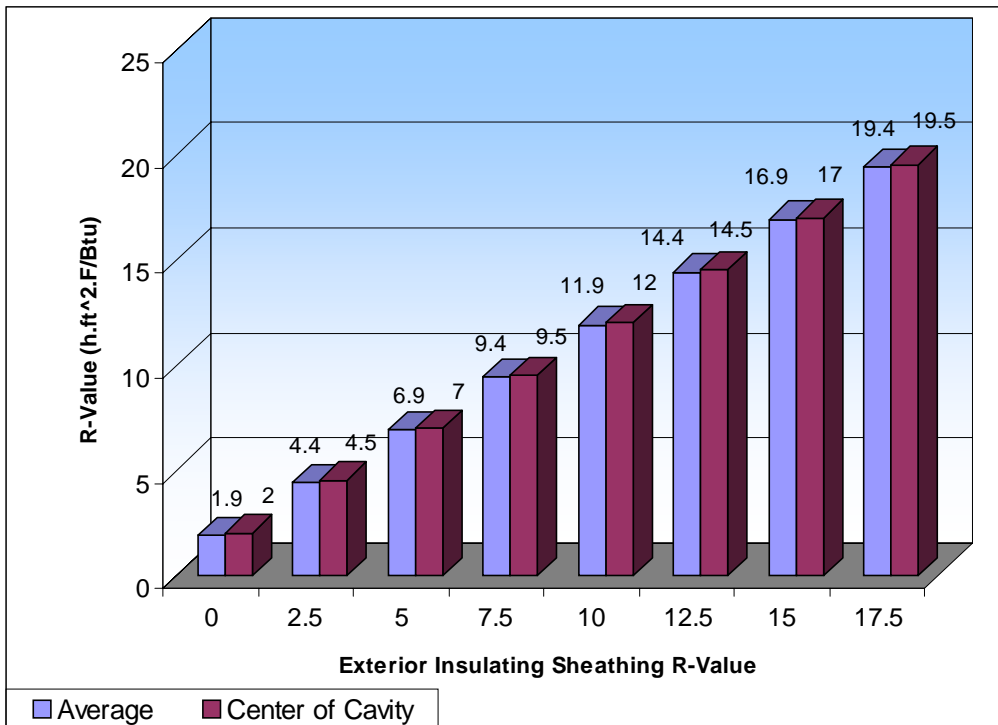


Figure 4 – Average Wall R-Value for Steel-Framed Walls with R-11 Cavity and Exterior Insulating Sheathing

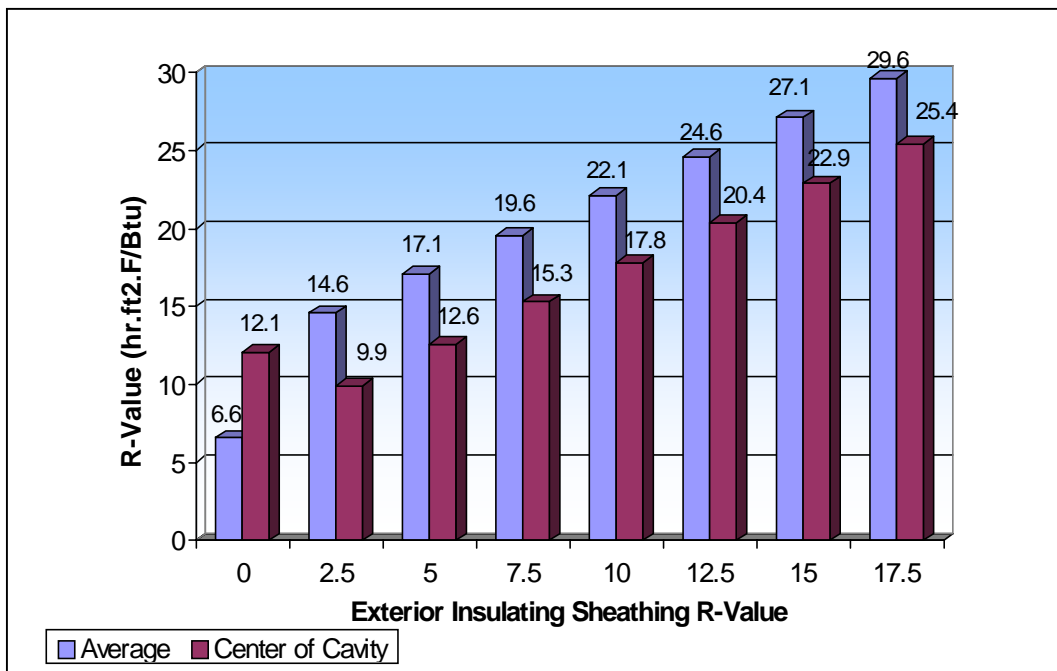


Figure 5 – Average Wall R-Value for Steel-Framed Walls with Different Levels of Exterior Insulating Sheathing

Thermal Performance of Slit-Web Steel Wall Studs



EVALUATION OF SELECTED THERMAL SOLUTIONS

Available technologies dealing with improving the thermal effectiveness of cold-formed steel framing were reviewed and grouped into five groups of options, representing several potential wall details as follows:

Frame Insulating Fitting	Thermal barriers on stud interior- or exterior-side flange under drywall, especially thin sections
Insulating Coating	Rigid insulation installed on interior or exterior side, with attention to cost and improving construction details
Stud Modification	Modified steel stud shapes, especially slotted or punched web designs
Wall System Modification	Complete wall sections that combine insulation and framing members
Structural/Insulating Panels	Use of sheathing with combined structural and insulation properties on outside of stud
Others	All others

A detailed description of each of the options considered is contained in Appendix A. A comprehensive review process was performed on the options listed in Table 1.

Design Option Review Process

Information on the options collected and created was summarized on a spreadsheet. The spreadsheet design allows either quantitative or qualitative input of such information as cost data, and calculates a benefit to cost ratio to help in the assessment and ranking of options. Assessment of the design options was based on:

- Approximate incremental effectiveness (R-value over base)
- Range of incremental cost (labor and materials)
- Impact on wall structural integrity
- Impact on ease of construction (“constructability”)
- Suitability for various climate regions, other code issues
- Potential impact on ghosting
- Potential impact on condensation
- Other factors affecting market acceptance

Assessment of these qualities of the design options was made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

½” plywood sheathing
3 ½” 18 gauge steel framing, 24 inches on center
R-13 fiberglass batt insulation
½” gypsum board

Builders and other industry professionals were contacted for their input on the design options and their merits.

Thermal Performance of Slit-Web Steel Wall Studs



Specific information listed in the spreadsheet for each option is:

- Design option name and identification number
- Best available estimate of additional R-value over the baseline system (not the R-value of the material). The added R-value for each option was obtained from research reports, manufacturer's catalogs (where available), or finite element models.
- Whether the wall system with this option totals R-13 or greater.
- Whether the wall system with this option, plus 1" of XPS foam totals R-19 or greater.
- First cut estimates of material and labor cost premiums (cents/ft²) over baseline, if available. The cost for each option was calculated using the 1998 RS Means.
- Total cost premium in a range of: none, low, medium, high or "value" (cost savings). These could be entered directly into the spreadsheet if quantitative data were not available. The spreadsheet translated these ranges into specific values to be used for the cost/benefit ratio.
- Thermal premium/cost premium ratio. If the cost premium is zero, disproportionately larger values of the ratio are assigned, to represent the much higher market attractiveness of the option.
- Structural impact – Positive, neutral or negative impact on structural strength with respect to the baseline system.
- Constructability impact – Impact of the option on the ease of construction, relative to the baseline system. This is intended to evaluate those construction-related factors that are not taken into account in the labor cost premium estimates. Constructability impact was done by obtaining builders' and framers input and experience.
- Condensation impact – Estimated impact of the option on the propensity toward collection of condensation inside the wall, relative to the baseline system. This judgment was not based on thermal analysis; generally, if a significant amount of insulation value was added to the outside of the wall, the option was judged to be positive in impact.
- Ghosting impact – The impact of the option on reducing the tendency of stripes to form over time on the inside surface of the wallboard. Generally, if significant insulation was added between the inside surface of the stud and the wallboard, the option was judged to have a positive impact. Analysis, comparison, research reports, or finite element models were used in determining the structural and ghosting impact (refer to Appendix B).
- Zone suitability – Suitability of the wall with that option for use in either hot, cold or transitional climates, based on judgments on the clear wall R-values required for certain heating degree day climates. Note that if a wall using a particular option meets the requirements for a cold zone, for instance, it also meets (exceeds) the requirements for a transition zone or hot zone.
- Design category – The general type of design option, using the categories described above.

Using the spreadsheet and other information tools, both quantitative and qualitative information were taken into account to assess the most promising options and categories of options. Specifically, three distinct types of criteria were evaluated:

- Cost/benefit ratio (from the design option summary spreadsheet)
- Qualitative information on criteria such as constructability (from the spreadsheet and other sources)
- In what geographic zone the option, or set of options, would be suitable. An effort was made to see that at least some options would be chosen for research that would be useful in cold geographic regions, using the criteria established in the spreadsheet.

The goal was not the selection of specific individual options which is necessary for testing phase, but rather a few select categories of options, or parts of categories, for evaluation and optimization during the analysis process. Also, options were not chosen if they were in common use and did not merit further research. For

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instance, the use of rigid foam insulation over outside sheathing was not chosen, since it is a common practice and it was felt that there were areas for further research that were more promising.

The results of the review process are listed in Tables 2 and 3. Two-dimensional finite element modelings were used to screen candidate assemblies prior to conducting hotbox testing. At the same time economic analysis were also conducted to determine the cost of the different approaches. The results were used to determine what wall sections will be constructed and tested in a calibrated hot box.

Rationale for Design Choices

The information on all the properties, for the selected wall sections, was put into table form to allow comparison between options. The figure of merit, “total cost premium” (as shown in Table 2) was calculated for all sections. From this data, a summary table with a narrower list of options was also developed, with a simplified system of ranking attributes (Ranked 1-5) (refer to Table 4). This facilitated easy comparison between different types of options. From observation, generalizations were made about the relative merits of the wall sections. For instance, it was judged that the most cost-effective “near wood equivalents” (neglecting constructability merit) were 1) a slit or slotted web and track; 2) 1” expanded polystyrene exterior sheathing; and 3) use of a foam cap on the flange. For an R-value of 18, the lowest cost option was use of a slit/slotted web stud with ½” exterior polyisocyanurate sheathing.

Using the above review process, four analysis topics were chosen representing the most promising research directions for thermal solutions to steel-framed wall heat transfer problems:

- Modified stud shapes & wall sections
- Wall systems using thermal tape-type configurations
- Wall systems using interior rigid foam
- Structural insulation systems

One of the most influential drivers in the choice of option groups was cost. The use of steel studs with modified shapes (slots, ridges), for instance, was not estimated to have a significant cost impact. Thermal tape has the potential for low cost, as does the use of interior foam sheets, if construction details are optimized. Structural insulation systems have the potential for actually lowering the construction cost, depending on material availability and the design, but there are many institutional and other barriers that would have to be overcome for widespread use.

Some of the groups of options chosen do not have the capability of meeting the overall clear wall R-value criteria used on their own. For example, the use of a slotted-web stud alone, according to the option summary spreadsheet, would increase the wall section thermal resistance by only R-2.0 or 2.5. However, significant potential exists for the use of multiple options (“hybrids”) that together will add little or no cost, but provide significant additional R-value. For instance, the use of certain types of thermal tape along with slotted web studs could provide additional insulation of R-5 or so, with little additional cost (reference option 10 in Table 4).

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Table 2 – Analysis Summary of Steel Frame Thermal Isolation Options

Option No.	Design Option/Combination	Thermal Premium (R-Value)	Wall Total of R-13	Wall Total of R-19 w/1" Foam	Material Cost Premium (cents/ft ²)	Labor Cost Premium (cents/ft ²)	Total Cost Premium	Thermal Premium/Cost Premium
1	Snap-Cap (2")	7	Yes	Yes	7.5	18.0	Medium	0.2
2	Astec Ceramic Ins. Coating	0.1	No	No	0.0	50.0	Medium	0.0
3a	Double Wall Metal Track	5	Yes	No			High	0.1
3b	Double Wall Insulated Track	6	Yes	Yes			High	0.1
4	Slotted Web (Delta)	2.5	No	No	0.0	0.0	None	5.0
5a	Rigid Sheathing (1") Polystyrene	5	Yes	n/a	45.0	8.0	High	0.1
5b	Rigid Sheathing (2")	10	Yes	n/a			High	0.2
5c	Rigid Sheathing (2") with lathe/glue	10	Yes	n/a			High	0.2
5d	Rigid Sheathing (2") without plywood	9	Yes	n/a			High	0.1
5e	Rigid Sheathing (1") Isocyanurate	7.2	Yes	n/a			High	0.1
6	Ridged Flange	1.13	No	No	0.0	0.0	None	2.3
7	Dimpled Flange	0.6	No	No	0.0	0.0	None	1.2
8a	Circular Slot Web	2	No	No	0.0	0.0	None	4.0
8b	Circ. Slot Web w/ Sprayed Foam	3	No	No			High	0.0
8c	Circ. Slot Web w/ Ridge & Foam	5	Yes	No			High	0.1
8d	Circ. Slot Web w/ Interior Foam/Z	5.5	Yes	No			Medium	0.1
8e	Circ. Slot Web w/ Ridge & Cellulose	4	No	No			Low	0.3
8f	Circ. Slot Web w/ Thermal Tape	5	Yes	No	11.0	5.8	Low	0.4
8g	Circ. Slot Web w/ Foil-backed Wallboard	3	No	No	10.0	0.0	Low	0.2
8h	Circ. Slot Web w/ Foil-Faced Insulation	3	No	No	10.0	0.0	Low	0.2
8i	Circ. Slot Web w/ Therm Tape & Foil Insul	6	Yes	Yes	21.0	5.8	Medium	0.2
9a	Furring Strips	1	No	No			Low	0.1
9b	Furring Strips w/ foil-backed ins.	2	No	No			Medium	0.1
9c	Furring Strips w/ Urethane Foam	5	Yes	No			High	0.1

¹ Thermal premium is estimated R-value above that of a baseline steel stud wall of about R-8 (4'x8' section), using 1/2" plywood, 3 1/2" studs, R-13 fiberglass batts, 1/2" drywall.

² Cost premium is estimated cost of construction above baseline wall; if numerical data is shown, total cost premium is "High" if above 50 cents/ft², "Medium" if between 25 and 50 cents/ft², "Low" if below 25 cents/ft², "Value" if cost is less than baseline.

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Table 2 – Analysis Summary of Steel Frame Thermal Isolation Options (cont.)

Option No.	Design Option/Combination	Thermal Premium (R-Value)	Wall Total of R-13	Wall Total of R-19 w/1" Foam	Material Cost Premium (cents/ft ²)	Labor Cost Premium (cents/ft ²)	Total Cost Premium	Thermal Premium/Cost Premium
9d	Furring Strips w/ Spray-in Cellulose	3.5	No	No			Medium	0.1
9e	Furring Strips w/ Cellulose & Slotted Stud	5	Yes	No			Medium	0.1
9f	Furring Strips w/ Foam & Slotted Stud	8	Yes	Yes			High	0.1
9g	Furring Strips w/ EESI-Stud	4.7	No	No			Medium	0.1
10a	EESI-Stud (Tri-Chord)	3.7	No	No	2.5	5.0	Low	0.3
10b	EESI-Stud w/ Thermal Tape	6.2	Yes	Yes	13.5	10.8	Low	0.5
11a	Struct. Insul - Cellulosic Hardboard	2	No	n/a		0.0	Low	0.2
11b	Struct. Insul - CBS Sheathing (1")	6.6	Yes	n/a	50.0	0.0	Medium	0.2
11c	Struct. Insul (CBS) w/ Slotted Web	8.6	Yes	n/a	50.0	0.0	Medium	0.2
11d	Struct. Insul (CBS) w/ Slot Web & 26	9.6	Yes	n/a	50.0	0.0	Medium	0.3
11e	Struct. Insul (Celotex Thermax) w/ Slot Web	9	Yes	n/a	50.0	0.0	Medium	0.2
11f	Struct. Insul (E'NRGY 2 Nailboard)	6.6	Yes	n/a	50.0	0.0	Medium	0.2
12	Thermal Tape	2.5	No	No	11.0	5.8	Low	0.2
13	SuperTherm Insulating Coating	0.1	No	No	56.0	11.0	High	0.0
14	Metal/Foam Laminate Sheathing	6.6	Yes	n/a		0.0	Low	0.5
15	Foil-Backed Wallboard	1	No	No	10	0	Low	0.1
16	Offset Framing	3	No	No			High	0.0
17	Broken Web	4.5	No	No			High	0.1
18	Hybrid Stud	5	Yes	No			Medium	0.1
19a	Panelized Walls (Thermastructure)	6.1	Yes	Yes	0.0	0.0	None	12.2
19b	Panelized Wall w/ ExcelBoard less Plywood	7.8	Yes	Yes			None	15.6
20	Foamed Cement/Metal Framing	1.5	No	No			Low	0.1
21a	PVC Clip	3.4	No	No			Low	0.3

¹ Thermal premium is estimated R-value above that of a baseline steel stud wall of about R-8 (4'x8' section), using 1/2" plywood, 3 1/2" studs, R-13 fiberglass batts, 1/2" drywall.

² Cost premium is est'd cost of construction above baseline wall; if numerical data is shown, total cost premium is "High" if above 50 cents/ft², "Medium" if between 25 and 50 cents/ft², "Low" if below 25 cents/ft², "Value" if cost is less than baseline.

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Table 2 – Analysis Summary of Steel Frame Thermal Isolation Options (cont.)

Option No.	Design Option/Combination	Thermal Premium (R-Value)	Wall Total of R-13	Wall Total of R-19 w/1" Foam	Material Cost Premium (cents/ft ²)	Labor Cost Premium (cents/ft ²)	Total Cost Premium	Thermal Premium/Cost Premium
21b	PVC Clip w/ Spray-in Foam	5	Yes	No			High	0.1
21c	PVC Clip w/ Spray-in Cellulose	4	No	No			Medium	0.1
21d	PVC Clip w/ Oversized Foil-Faced Batt	5	Yes	No			Medium	0.1
22a	Insulated Drywall	7.2	Yes	Yes	50.0	0.0	Medium	0.2
22b	Insulated Drywall w/ Slotted Web	9.5	Yes	Yes	50.0	0.0	Medium	0.3
23	Spray-in Foam	1	No	No			High	0.0
24	ExcelBoard Structural Insulation	2	No	n/a	50.0	0.0	Medium	0.1
25	Diversitec Structural Insulation	4	No	n/a	30.0	0.0	Medium	0.1
26a	Fiberglass Batt w/ Foil over Flange	1	No	No	0.0	0.0	None	2.0
26b	Fiberglass Batt w/ Foil over Slotted Web	3	No	No	0.0	0.0	None	6.0
27a	Gentec Insulated Siding	3.8	No	No			Medium	0.1
27b	AmazingWall Insulated Siding	4.5	No	No			Medium	0.1
27c	TechWall Insulated Siding	4	No	No			Medium	0.1
27d	TechWall Ins. Siding w/ Batt over Flange	5	Yes	No			Medium	0.1
27e	TechWall Ins. Siding w/ Slotted Web	6	Yes	Yes			Medium	0.2
27f	TechWall Siding w/ Batt & Slotted Web	7	Yes	Yes			Medium	0.2
28a	Interior Rigid Foam w/ Z Strip	3.5	No	No			Medium	0.1
28b	Interior Rigid Foam w/ Hat Channel	3.5	No	No			Medium	0.1
28c	Inter. Rigid Foam w/ Z & Foil-Faced Insul	4.5	No	No			Medium	0.1

¹ Thermal premium is estimated R-value above that of a baseline steel stud wall of about R-8 (4'x8' section), using 1/2" plywood, 3 1/2" studs, R-13 fiberglass batts, 1/2" drywall.

² Cost premium is est'd cost of construction above baseline wall; if numerical data is shown, total cost premium is "High" if above 50 cents/ft², "Medium" if between 25 and 50 cents/ft², "Low" if below 25 cents/ft², "Value" if cost is less than baseline.

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Table 3 – Evaluation Summary of Steel Frame Thermal Isolation Options

Option No.	Design Option/Combination	Structural Impact	Constructability Impact	Condensation Impact	Ghosting Impact	Zoning Suitability	Design Category
1	Snap-Cap (2")	Negative	Negative	Neutral	Positive	Cold	Frame Insulating Fitting
2	Astec Ceramic Ins. Coating	Neutral	Neutral	Neutral	Neutral	None	Insulating Coating
3a	Double Wall Metal Track	Negative	Neutral	Neutral	Positive	Transition	Wall System Modification
3b	Double Wall Insulated Track	Negative	Negative	Neutral	Positive	Cold	Wall System Modification
4	Slotted Web (Delta)	Neutral	Neutral	Neutral	Neutral	Hot	Stud Modification
5a	Rigid Sheathing (1") Polystyrene	Positive	Neutral	Positive	Positive	Transition	Structural/Insulating Panels
5b	Rigid Sheathing (2")	Positive	Negative	Positive	Positive	Cold	Structural/Insulating Panels
5c	Rigid Sheathing (2") with lathe/glue	Positive	Negative	Positive	Positive	Cold	Structural/Insulating Panels
5d	Rigid Sheathing (2") without plywood	Negative	Negative	Positive	Positive	Cold	Structural/Insulating Panels
5e	Rigid Sheathing (1") Isocyanurate	Positive	Neutral	Positive	Positive	Cold	Structural/Insulating Panels
6	Ridged Flange	Neutral	Negative	Neutral	Neutral	None	Stud Modification
7	Dimpled Flange	Neutral	Neutral	Neutral	Neutral	None	Stud Modification
8a	Circular Slot Web	Neutral	Neutral	Neutral	Neutral	Hot	Stud Modification
8b	Circ. Slot Web w/ Sprayed Foam	Positive	Neutral	Neutral	Neutral	Hot	Hybrid
8c	Circ. Slot Web w/ Ridge & Foam	Neutral	Negative	Neutral	Positive	Transition	Hybrid
8d	Circ. Slot Web w/ Interior Foam/Z	Neutral	Positive	Neutral	Positive	Cold	Hybrid
8e	Circ. Slot Web w/ Ridge & Cellulose	Neutral	Neutral	Neutral	Positive	Transition	Hybrid
8f	Circ. Slot Web w/ Thermal Tape	Neutral	Neutral	Neutral	Positive	Transition	Hybrid
8g	Circ. Slot Web w/ Foil-backed Wallboard	Neutral	Neutral	Neutral	Positive	Hot	Hybrid
8h	Circ. Slot Web w/ Foil-Faced Insulation	Neutral	Neutral	Neutral	Positive	Hot	Hybrid
8i	Circ. Slot Web w/ Therm Tape & Foil Insul	Neutral	Neutral	Neutral	Positive	Cold	Hybrid
9a	Furring Strips	Neutral	Neutral	Neutral	Positive	None	Wall System Modification
9b	Furring Strips w/ foil-backed ins.	Neutral	Neutral	Neutral	Positive	Hot	Hybrid
9c	Furring Strips w/ Urethane Foam	Positive	Neutral	Neutral	Positive	Transition	Hybrid

¹ Constructability impact is assessed based on whether significant additional time would be required to assemble framing or install utilities, which time is not accounted under labor cost.

² Condensation impact is generally assessed as positive if insulation value is being added to the outside of the wall.

³ Ghosting impact is the affect the option has on wall "stripping". It is assessed as positive if the option contributes at least R-3 or there is substantial insulation on the inside wall.

⁴ Zone suitability indicates whether the option would render a wall suitable for use in one of three regions based on total R-value; "Cold" if total R-value of 13.5 or more, "Transition" of 11.5 - 13.5, "Hot" if 9.5 - 11.5, "None" if less than 9.5.

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Table 3 – Evaluation Summary of Steel Frame Thermal Isolation Options (cont.)

Option No.	Design Option/Combination	Structural Impact	Constructability Impact	Condensation Impact	Ghosting Impact	Zoning Suitability	Design Category
9d	Furring Strips w/ Spray-in Cellulose	Neutral	Neutral	Neutral	Positive	Transition	Hybrid
9e	Furring Strips w/ Cellulose & Slotted Stud	Neutral	Neutral	Neutral	Positive	Transition	Hybrid
9f	Furring Strips w/ Foam & Slotted Stud	Positive	Neutral	Neutral	Positive	Cold	Hybrid
9g	Furring Strips w/ EESI-Stud	Neutral	Negative	Neutral	Positive	Transition	Hybrid
10a	EESI-Stud (Tri-Chord)	Neutral	Negative	Neutral	Positive	Transition	Stud Modification
10b	EESI-Stud w/ Thermal Tape	Neutral	Negative	Neutral	Positive	Cold	Hybrid
11a	Struct. Insul - Cellulosic Hardboard	Negative	Neutral	Positive	Neutral	Hot	Structural/Insulating Panels
11b	Struct. Insul - CBS Sheathing (1")	Neutral	Neutral	Positive	Positive	Cold	Structural/Insulating Panels
11c	Struct. Insul (CBS) w/ Slotted Web	Neutral	Neutral	Positive	Positive	Cold	Hybrid
11d	Struct. Insul (CBS) w/ Slot Web & 26	Neutral	Neutral	Positive	Positive	Cold	Hybrid
11e	Struct. Insul (Celotex Thermax) w/ Slot Web	Neutral	Neutral	Positive	Positive	Cold	Hybrid
11f	Struct. Insul (E'NRGY 2 Nailboard)	Neutral	Neutral	Positive	Positive	Cold	Structural/Insulating Panels
12	Thermal Tape	Neutral	Neutral	Neutral	Neutral	Hot	Frame Insulating Fitting
13	SuperTherm Insulating Coating	Neutral	Neutral	Neutral	Neutral	None	Insulating Coating
14	Metal/Foam Laminate Sheathing	Neutral	Neutral	Positive	Positive	Cold	Structural/Insulating Panels
15	Foil-Backed Wallboard	Neutral	Neutral	Neutral	Neutral	None	Other - Rad/Conducting Coat
16	Offset Framing	0.0	Neutral	Neutral	Neutral	Positive	Hot
17	Broken Web	0.1	Negative	Neutral	Neutral	Positive	Transition
18	Hybrid Stud	0.1	Neutral	Neutral	Neutral	Positive	Transition
19a	Panelized Walls (Thermastructure)	12.2	Neutral	Negative	Positive	Positive	Cold
19b	Panelized Wall w/ ExcelBoard less Plywood	15.6	Neutral	Negative	Positive	Positive	Cold
20	Foamed Cement/Metal Framing	0.1	Neutral	Neutral	Neutral	Neutral	Hot
21a	PVC Clip	0.3	Neutral	Negative	Neutral	Positive	Hot
21b	PVC Clip w/ Spray-in Foam	0.1	Neutral	Negative	Neutral	Positive	Transition
21c	PVC Clip w/ Spray-in Cellulose	0.1	Neutral	Negative	Neutral	Positive	Transition

¹ Constructability impact is assessed based on whether significant additional time would be required to assemble framing or install utilities, which time is not accounted under labor cost.

² Condensation impact is generally assessed as positive if insulation value is being added to the outside of the wall.

³ Ghosting impact is the affect the option has on wall "striping". It is assessed as positive if the option contributes at least R-3 or there is substantial insulation on the inside wall.

⁴ Zone suitability indicates whether the option would render a wall suitable for use in one of three regions based on total R-value; "Cold" if total R-value of 13.5 or more, "Transition" of 11.5 - 13.5, "Hot" if 9.5 - 11.5, "None" if less than 9.5.

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Table 3 – Evaluation Summary of Steel Frame Thermal Isolation Options (cont.)

Option No.	Design Option/Combination	Structural Impact	Constructability Impact	Condensation Impact	Ghosting Impact	Zoning Suitability	Design Category
21d	PVC Clip w/ Oversized Foil-Faced Batt	0.1	Neutral	Negative	Neutral	Positive	Transition
22a	Insulated Drywall	0.2	Neutral	Negative	Neutral	Positive	Cold
22b	Insulated Drywall w/ Slotted Web	0.3	Neutral	Negative	Neutral	Positive	Cold
23	Spray-in Foam	0.0	Positive	Neutral	Neutral	Neutral	None
24	ExcelBoard Structural Insulation	0.1	Negative	Neutral	Positive	Positive	Hot
25	Diversitec Structural Insulation	0.1	Neutral	Neutral	Positive	Positive	Transition
26a	Fiberglass Batt w/ Foil over Flange	2.0	Neutral	Neutral	Neutral	Positive	None
26b	Fiberglass Batt w/ Foil over Slotted Web	6.0	Neutral	Neutral	Neutral	Positive	Hot
27a	Gentec Insulated Siding	0.1	Neutral	Neutral	Positive	Positive	Transition
27b	Amazing Wall Insulated Siding	0.1	Neutral	Neutral	Positive	Positive	Transition
27c	TechWall Insulated Siding	0.1	Neutral	Neutral	Positive	Positive	Transition
27d	TechWall Ins. Siding w/ Batt over Flange	0.1	Neutral	Neutral	Positive	Positive	Transition
27e	TechWall Ins. Siding w/ Slotted Web	0.2	Neutral	Neutral	Positive	Positive	Cold
27f	TechWall Siding w/ Batt & Slotted Web	0.2	Neutral	Neutral	Positive	Positive	Cold
28a	Interior Rigid Foam w/ Z Strip	0.1	Neutral	Positive	Neutral	Positive	Transition
28b	Interior Rigid Foam w/ Hat Channel	0.1	Neutral	Positive	Neutral	Positive	Transition
28c	Inter. Rigid Foam w/ Z & Foil-Faced Insul	0.1	Neutral	Positive	Neutral	Positive	Transition

¹ Constructability impact is assessed based on whether significant additional time would be required to assemble framing or install utilities, which time is not accounted under labor cost.

² Condensation impact is generally assessed as positive if insulation value is being added to the outside of the wall.

³ Ghosting impact is the affect the option has on wall "striping". It is assessed as positive if the option contributes at least R-3 or there is substantial insulation on the inside wall.

⁴ Zone suitability indicates whether the option would render a wall suitable for use in one of three regions based on total R-value; "Cold" if total R-value of 13.5 or more, "Transition" of 11.5 - 13.5, "Hot" if 9.5 - 11.5, "None" if less than 9.5.

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Table 4 - Steel Frame, Whole Wall Thermal Isolation Design Options Assignment List

Option	Wall Construction	Thermal	Structural	Cost	Constructability	Manufacturing/ Risk	Average
1	1" Extruded Polystyrene Sheathing (XPS) Outside	4	3	2	2	5	3.2
2	2" Foam Cap	4	3	3	2	5	3.4
3	1/4" Fanfold Insulation on Flange	1	4	2	4	5	3.2
4	1/4" Foam Tape (R-3) on Flange	2	4	3	4	3	3.2
5	Slit Web Stud and Track (9 Row)	2	2	4	5	4	3.4
6	Slit Web Stud and Track, 50 ksi, 33 mil	2	4	5	5	3	3.8
7	Slit Web Stud & Track, 1 3/4" Flange, 5/8" Lip	2	4	4	5	3	3.6
8	Slit Web Stud & Track, 1 3/4" Flange, 5/8" Lip, 40 ksi	2	5	4	5	3	3.8
9	Slit Web Stud & Track, 1 3/4" Flange, 5/8" Lip, 50 ksi	2	5	4	5	3	3.8
10	Slit Web Stud and Track, 50 ksi, 33 mil + 1/2" Polyiso	5	4	2	4	3	3.6
11	Extruded Slot Stud/Track (7 Row)	2	4	4	4	2	3.2
12	Extruded Slot Stud/Track + Foam Tape	3	4	3	4	2	3.2
13	Extruded Slot Stud/Track + 1/2" Polyiso Sheathing	5	4	2	4	2	3.4
14	Extruded Slot Stud/ Track, 40 ksi + 1/2" Polyiso	5	5	2	4	2	3.6
15	1" Expanded Polystyrene Sheathing (EPS) Inside	2	4	1	1	5	2.6
16	CBS Board (Reinforced 1/2" Polyiso)	4	2	3	4	3	3.2

Notes:

- 2) 1 indicates "Worst"; 5 indicates "Best".
- 2) All walls 2x4, 24"o.c., 33 ksi, 43 mil, unless otherwise noted
- 3) Averages are calculated based on an even weighting of all attributes
- 4) R-values in thermal column range from about R-9.7 to R-17.4

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ANALYSIS OF THERMAL OPTIONS SELECTED

Each of the four areas described in the previous section involved analyses tailored, both in their content and depth, to the type of option and its unique requirements. Although the focus of the investigations was on practical solutions, attention was paid to potential longer-term opportunities.

Analysis of Modified Stud Shapes and Wall Sections

A lot of emphasis was put on the analysis of modified stud shapes. Such modifications as slotted webs and modified flanges were covered, with an emphasis on those changes that would maintain or reduce price and enhance constructability. The research can be divided into three areas:

- Thermal evaluation of modified stud configurations. First, the thermal properties of steel studs alone – that is, not as part of a built-up wall – were evaluated using three-dimension finite element analysis (3-D FEA). Analysis of both existing and new designs were covered, including such modifications as slotted web designs, ridged flanges and dimpled flanges.
- Limited thermal, structural and cost optimization of selected modified studs. Promising designs from the above thermal work was examined to look for ways to simultaneously optimize thermal and structural properties, using FEA and other tools.
- Thermal and cost optimization of wall systems with modified studs, using 2-D FEA, cost & constructability guidelines. The most attractive stud designs were evaluated in a number of configurations with other mitigation options in clear wall cross-sections.

Analysis of Thermal Tape-Type Wall Sections

Flexible, adhesive-backed, high-resistivity foam tapes that can be applied to the stud flanges were the focus of this analysis. However, other similar promising insulating systems, such as the application of strips of foam to flanges, were also investigated. There were two areas of research:

- Collection of thermal property data on newly developed materials. Some thermal tapes now under development were investigated, and other potential materials researched.
- Thermal and cost optimization of wall systems with thermal tape, using 2-D FEA, as well as cost and constructability guidelines.

Analysis of Interior Rigid Foam Wall Sections

Wall systems using rigid foam sheets and various installation configurations were investigated. The emphasis was on inexpensive materials and modifications to the systems and installation techniques that have the potential to reduce overall building cost or enhance constructability. The work involved thermal and cost optimization of wall systems using two-dimensional finite element analysis, cost & constructability guidelines.

Analysis of Structural Insulation Systems

Outside sheathing systems that carry both structural and insulating properties in one product have the potential to eliminate thermal concerns without significant cost or constructability impact. The evaluation of structural systems was composed of two subtasks:

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- Limited thermal, structural and cost optimization of structural insulated sheathing systems (Evaluation was of the sheathing itself rather than wall cross-sections.) Products that are currently commercially available were evaluated, and a limited amount of analysis on potential new products performed.
- Thermal and cost optimization of wall systems with structural insulation, using 2-D FEA, cost & constructability guidelines. Wall cross-sections were analyzed, using the most promising sheathing products investigated above.

Table 5 contains a summary of the results of the analysis of the thermal options considered above.

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Table 5 - Summary of Steel Wall Thermal Isolation Design Options

Option No.	Design Option/Combination	R-Value of Wall	R-Value w/1" XPS Foam	Material Cost (\$/Wall)	Labor Cost (\$/Wall)	Total Cost (\$/Wall)	Added Cost per R-Value	Constructability Impact	Zone Suitability
1	Baseline Wood 2x4, 24" o.c.	12.7	18.7	\$51.16	\$65.70	\$116.86	n/a	Small	Transition
2	Baseline Steel 350S162-43, 24" o.c.	8.0	14.0	\$77.06	\$81.76	\$158.82	n/a	Small	None
3	1/2" EPS on Exterior	11.0	n/a	\$83.72	\$99.49	\$183.21	8.1	None	Hot
4	1" EPS on Exterior	13.3	n/a	\$89.20	\$99.49	\$188.69	5.6	None	Transition
5	2" EPS on Exterior	18.5	n/a	\$100.12	\$101.26	\$201.38	4.1	None	Cold
6	1/2" XPS on Exterior	12.1	n/a	\$92.19	\$99.49	\$191.68	8.0	None	Transition
7	1" XPS on Exterior	14.4	n/a	\$95.14	\$99.49	\$194.63	5.6	None	Cold
8	2" XPS on Exterior	19.6	n/a	\$113.03	\$101.26	\$214.29	4.8	None	Cold
9	1/2" Polyisocyanurate on Exterior	14.2	n/a	\$91.17	\$99.49	\$190.66	5.1	None	Cold
10	1" Polyisocyanurate on Exterior	16.5	n/a	\$102.56	\$99.49	\$202.05	5.1	None	Cold
11	2" Polyisocyanurate on Exterior	21.7	n/a	\$120.19	\$101.26	\$221.45	4.6	None	Cold
12	2" Foam Cap on Exterior	15.3	21.3	\$91.06	\$90.90	\$181.96	3.2	None	Cold
13	1/4" Fanfold on Interior	9.7	15.7	\$78.22	\$109.46	\$187.68	17.0	Small	Hot
14	R-2 Foam Tape on Interior	10.2	16.2	\$85.46	\$97.79	\$183.25	11.1	Small	Hot
15	R-3 Foam Tape on Interior	10.9	16.9	\$85.46	\$97.79	\$183.25	8.4	None	Hot
16	R-5 Foam Tape on Interior	11.4	17.4	\$85.46	\$97.79	\$183.25	7.2	None	Hot
17	Slit Web Stud, 3" 6 row slits, 4" solid end	10.2	16.2	\$77.06	\$81.76	\$158.82	0.0	None	Hot
18	Slit Web Stud, 3" 9 row slits, 4" solid end	10.4	16.4	\$77.06	\$81.76	\$158.82	0.0	None	Hot
19	Slit Web Stud, 3" 6 row slits, 2" solid end, 40ksi	10.5	16.5	\$77.06	\$81.76	\$158.82	0.0	None	Hot
20	Slit Web Stud, 3" 9 row slits, 2" solid end, 40ksi	10.8	16.8	\$77.06	\$81.76	\$158.82	0.0	None	Hot
21	Slit Web Stud & Track, 3" 9 row slits, 2"	11.7	17.7	\$77.06	\$81.76	\$158.82	0.0	None	Transition
22	Slit Web Stud, 3" 9 row slits, 2" solid end, 50 ksi	10.8	16.8	\$78.61	\$81.76	\$160.37	0.6	None	Hot
23	Slotted Web Stud, 3" 7 row, 2" solid end	10.6	16.6	\$77.06	\$81.76	\$158.82	0.0	None	Hot
24	Slotted Web Stud, 3" 7 row, 2" solid end, 40ksi	10.6	16.6	\$77.06	\$81.76	\$158.82	0.0	None	Hot
25	Slotted Web Stud, 4" 7 row, 2" solid end, 40ksi	10.8	16.8	\$77.06	\$81.76	\$158.82	0.0	Small	Hot
26	Slotted Web Stud, 3" 7 row, 2" end, 40ksi, 33mil	10.9	16.9	\$69.12	\$75.13	\$144.25	-5.0	Small	Hot
27	Slotted Web Stud, 4" 7 row, 2" end, 40ksi, 33mil	11.1	17.1	\$69.12	\$75.13	\$144.25	-4.7	None	Hot

¹ Baseline steel stud wall is 8'x8' section using 1/2" plywood, 3 1/2" studs, R-13 fiberglass batts, 1/2" drywall.

² Constructability impact is assessed based on whether significant additional time would be required to assemble framing or install utilities, which time is not accounted under labor cost.

³ Zone suitability indicates whether the option would render a wall suitable for use in one of three regions based on total R-value; "Cold" if total R-value of 13.5 or more, "Transition" of 11.5 - 13.5, "Hot" if 9.5 - 11.5, "None" if less than 9.5.

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Table 5 - Summary of Steel Frame Thermal Isolation Options (cont.)

Option No.	Design Option/Combination	R-Value of Wall	R-Value w/1" XPS Foam	Material Cost (\$/Wall)	Labor Cost (\$/Wall)	Total Cost (\$/Wall)	Added Cost per R-Value	Constructability Impact	Zone Suitability
28	Slotted Web/Slit Track, 3", 7 row, 2" end	11.6	17.6	\$77.06	\$81.76	\$158.82	0.0	None	Transition
29	Slit Web #21 with R-2 Foam Tape	12.4	18.4	\$85.43	\$97.79	\$183.22	5.5	Small	Transition
30	Slit Web #21 with R-3 Foam Tape	12.7	18.7	\$85.43	\$97.79	\$183.22	5.2	Small	Transition
31	Slit Web #21 with 1/4" Fanfold	12.0	18.0	\$78.22	\$109.46	\$187.68	7.2	Small	Transition
32	Slotted Web #28 with R-2 Foam Tape	12.3	18.3	\$85.43	\$97.79	\$183.22	5.7	Small	Transition
33	Slotted Web #28 with R-3 Foam Tape	12.6	18.6	\$85.43	\$97.79	\$183.22	5.3	Small	Transition
34	Slit Web #21 with 1/2" Polyiso on Exterior	17.5	n/a	\$91.17	\$99.49	\$190.66	3.4	Small	Cold
35	Slit Web #21 with 1" XPS on Exterior	17.7	n/a	\$95.14	\$99.49	\$194.63	3.7	Moderate	Cold
36	Slotted Web #28 with 1/2" Polyiso on Exterior	17.4	n/a	\$91.17	\$99.49	\$190.66	3.4	Small	Cold
37	Slotted Web #28 with 1" XPS on Exterior	17.6	n/a	\$95.14	\$99.49	\$194.63	3.7	Moderate	Cold
38	Slotted Web #28 w/ 1" XPS (5% steel premium)	17.6	n/a	\$96.69	\$99.49	\$196.18	3.9	Moderate	Cold
39	Slit Web #21 w/ R-2 Tape and 1/2" Polyiso	18.2	n/a	\$99.57	\$115.52	\$215.09	5.5	Moderate	Cold
40	Slit Web #21 w R-2 Tape and 1" XPS	18.4	n/a	\$103.54	\$115.52	\$219.06	5.8	Moderate	Cold
41	Slotted Web #28 w/ R-2 Tape and 1/2" Polyiso	18.1	n/a	\$99.57	\$115.52	\$215.09	5.6	Moderate	Cold
42	Slotted Web #28 w/ R-2 Tape and 1" XPS	18.3	n/a	\$103.54	\$115.52	\$219.06	5.8	Moderate	Cold
43	20 ga., 50 ksi stud w/ 1" XPS (5% steel premium)	14.8	n/a	\$88.38	\$92.86	\$181.24	3.3	Moderate	Cold
44	20 ga 50 ksi slit web #21 w/ 1" XPS	18.0	n/a	\$88.38	\$92.86	\$181.24	2.2	Moderate	Cold
45	Slit web #21 with 3/4" lip (5% steel premium)	11.6	17.6	\$78.61	\$81.76	\$160.37	0.4	None	Transition
46	Slit web #21 with 1 3/4" flange and 5/8" lip	11.6	17.6	\$78.61	\$81.76	\$160.37	0.4	None	Transition
47	Slit web #21 with 1/4" added lip	11.6	17.6	\$78.61	\$81.76	\$160.37	0.4	None	Transition
48	Slit web #21 w/ 1 3/4" flange and 1/8" added lip	11.6	17.6	\$78.61	\$81.76	\$160.37	0.4	None	Transition
49	Slit web #21 with 1 3/4" flange, 5/8" lip, 50 ksi	11.6	17.6	\$80.16	\$81.76	\$161.92	0.9	None	Transition
50	Slit web #21, 50 ksi, 33 mil, 1/2" CBS sheathing	17.2	n/a	\$83.91	\$93.82	\$177.73	2.1	Small	Cold

¹ Baseline steel stud wall is 8'x8' section using 1/2" plywood, 3 1/2" studs, R-13 fiberglass batts, 1/2" drywall.

² Constructability impact is assessed based on whether significant additional time would be required to assemble framing or install utilities, which time is not accounted under labor cost.

³ Zone suitability indicates whether the option would render a wall suitable for use in one of three regions based on total R-value; "Cold" if total R-value of 13.5 or more, "Transition" of 11.5 - 13.5, "Hot" if 9.5 - 11.5, "None" if less than 9.5.

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SELECTION OF POTENTIAL THERMAL SOLUTION

A number of steel studs with modified webs were evaluated thermally using Finite Element Analysis (FEA). The analysis included both the evaluation of several broad categories of web modifications, and evaluation of specific designs, some of which are commercially available. The conclusion based on modeling is that the most thermally effective designs use thin (high ratio of length to width) slots, staggered along the width of the stud, to lengthen the thermal path. Stud webs of this design have been modeled as reducing heat transfer by 90% or more (refer to Table 6).

Overall wall sections, comprised of standard studs, modified studs, thermal tape, and other components were also evaluated using Finite Element Analysis (FEA) and spreadsheet analysis. This has:

- a) Enabled an evaluation of the most effective options,
- b) Indicated the upper limits of the thermal effects of a given option on overall wall R-value, and
- c) Indicated what level of component performance is required in order to meet desired overall wall R-values. For instance, a steel stud web with 90% reduced conductivity has been modeled as resulting in a wall section, given certain assumptions, with an R-value comparable to that of a wood-framed wall. Similarly, a thin thermal break between the stud flange and drywall with an R-value of 3 is modeled as being approximately equivalent to a wood-framed wall. Examination of the results of the hot box tests will allow confirmation and/or adjustment of the modeling results

Cost spreadsheets were constructed to evaluate and rank the costs of various wall sections. Lacking definitive information regarding the cost to manufacture new slotted web stud designs, certain assumptions were made to estimate the cost premiums for modified steel studs. Evaluations of wall section options were also made, or refined, in terms of how they affected aspects of house construction not accounted for directly in the cost spreadsheets, and what the potential manufacturing implications would be. Table 6 summarizes the results of the thermal modeling of the slit-web stud option with variable number of slits and size. The R-value for each option was determined using a finite element model.

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Table 6 - Thermal FEA Buildup for Slotted Web Studs

No.	Stud Type	Stud End Btu/sec-in ²	Stud Middle Btu/sec-in ²	Stud Utility Hole Btu/sec-in ²	Stud Overall Btu/sec-in ²	% Thermal Reduction Over Solid
1	Baseline solid web	0.00957	0.00957	none	0.00957	0.0%
2	Slit web 3", 6 row, solid center, 4" solid end	0.003051	0.0007223	0.0006816	0.001491326	84.4%
3	Slit web 3", 6 row, solid center, 2" solid end	0.002073	0.0007223	0.0006816	0.001165326	87.8%
4	Slit web 3", 9 row, slit center, 4" solid end	0.00957	0.0004117	0.0006816	0.001222686	87.2%
5	Slit web 3", 9 row, slit center, 2" solid end	0.00957	0.0004117	0.0006816	0.000841091	91.2%
6	Slit web 3", 11 row, slit center, 4" solid end	0.00957	0.0002737	0.0004278	0.00107568	88.8%
7	Slit web 3", 11 row, slit center, 2" solid end	0.00957	0.0002737	0.0004278	0.00068833	92.8%
8	Slit web 3", 8 row, solid center, 4" solid end	0.00957	0.0004281	0.0004278	0.00118987	87.6%
9	Slit web 3", 8 row, solid center, 2" solid end	0.00957	0.0004281	0.0004278	0.00080896	91.5%
10	Slit web 4", 11 row, slit center, 4" solid end	0.00957	0.0001544	0.0002465	0.00095918	90.0%
11	Slit web 4", 11 row, slit center, 2" solid end	0.00957	0.0001544	0.0002465	0.00056686	94.1%
12	Slot web 4", 7 row, slit center, 4" solid end	0.00957	0.000315	0.0005534	0.0011384	88.1%
13	Slot web 4", 7 row, slit center, 2" solid end	0.00957	0.000315	0.0005534	0.00075278	92.1%
14	Slot web 4.5", 7 row, slit ctr, 4" solid end	0.00957	0.0002532	0.000402	0.00106525	88.9%
15	Slot web 4.5", 7 row, slit ctr, 2" solid end	0.00957	0.0002532	0.000402	0.00067705	92.9%
16	Slot web 4.5", 7 row, slit ctr, 1.5" solid end	0.00957	0.0002532	0.000402	0.00058	93.9%
17	Slot web 4", 9 row, full width slits, 4" sol end	0.00957	0.0002135	0.0003107	0.00101447	89.4%
18	Slot web 4", 9 row, full width slits, 2" sol end	0.00957	0.0002135	0.0003107	0.00062462	93.5%
19	Slot web 4", 5 row, full width slits, 2" sol end	0.00957	0.0006532	0.0006930	0.00103346	89.2%
20	Slot web 4", 5 row, mods for mfg	0.00219	0.0007667	0.0007384	0.00093059	90.3%
21	5.5" Reinf slot 3", 9 row, mods for mfg	0.00347	0.0004691	0.0004811	0.00085084	91.1%
22	5.5" Reinf slot 3.5", 9 row, mods for mfg	0.00320	0.0003130	0.0003244	0.00068008	92.9%

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EXPERIMENTAL APPROACH

Based on the evaluation and analysis of the information developed on the wall sections, an initial set of ten thermal hot box tests were chosen, to verify the estimated R-values. The tests, conducted cover the following types of wall sections:

- Baseline steel wall
- Steel wall with a high-R foam tape
- Steel walls with “knife slit” shapes in stud webs
- Steel walls with a newly developed “extruded slot” pattern in the stud webs
- Steel walls with 5 ½” and 3 ½” stud widths
- Combinations of the above options, including use of thin exterior rigid foam sheathing

After the test results of the initial ten wall assemblies were evaluated, a revised slit-web stud was developed and a prototype was fabricated. Twelve additional wall assemblies utilizing the refined slit-web stud were tested in the hotbox apparatus. The two phases of testing are summarized below:

- Phase I:** Testing of ten wall assemblies using the Lindab slit-web stud (refer to option 4 in Appendix A). The stud configuration used for testing (Lindab slit-web stud) offered the needed reduction in thermal conductivity for a potential thermal solution. Fabrication of such a stud was costly, and therefore, the Lindab stud was used to obtain an initial assessment of the estimated R-value of the steel wall.
- Phase II:** Testing of 12 wall assemblies using a refined slit-web stud. The stud used in Phase I was refined to improve its structural characteristics (strength) as the slit web stud with slits similar to those of the Lindab stud were reported to have a reduced axial strength of nearly 50% when compared to a solid web stud [6].

Test Apparatus and Test Method

Testing was conducted at Oak Ridge National Laboratory (ORNL). The test assemblies were tested in accordance with ASTM C 1363-97 [2], "Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box" using the Oak Ridge National Laboratory Rotatable Guarded Hot Box (RGHB).

The test assemblies were installed into a specimen frame, which is mounted on a moveable dolly. The specimen frame has an aperture of 13-ft long by 10-ft high. The specimen frame/test assembly is inserted between two chambers of identical cross-section. The insertion of the test wall assembly between the chambers allows the chamber temperatures to be independently controlled. These chambers are designated as the climate (cold) and metering/guard (hot) chambers. A photograph, schematic of the RGHB and cross section of the RGB frame are shown in Figures 6, 7, and 8 respectively.

In the climate chamber, a full-size baffle is mounted approximately 10 in. from the test specimen assembly. Temperature control in this chamber is accomplished by the insertion of a refrigeration system and electrical resistance heaters in series with an array of air blowers. The external refrigeration system is operated continuously and cooled air is transferred from the refrigeration system through insulated flexible ducting into the rear of the climate chamber behind the baffle. Five centrifugal air blowers, installed in the climate chamber behind the baffle, are used to circulate the air through a bank of electrical resistance heaters and through the airspace between the baffle and test specimen assembly. Temperature control is accomplished by overcooling the air stream entering the climate chamber and

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then reheating this air stream with resistance heaters. The air velocity parallel to the climate side of the test specimen assembly is controlled by adjusting the input frequency to the air blowers. An anemometer continuously measures the wind speed in the airspace.



Figure 6 - Rotatable Guarded Hot Box

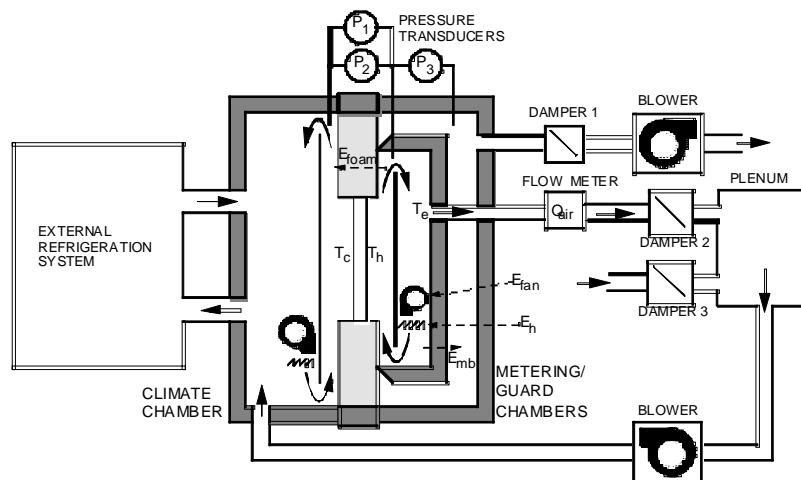


Figure 7 - Schematic of Rotatable Guarded Hot Box

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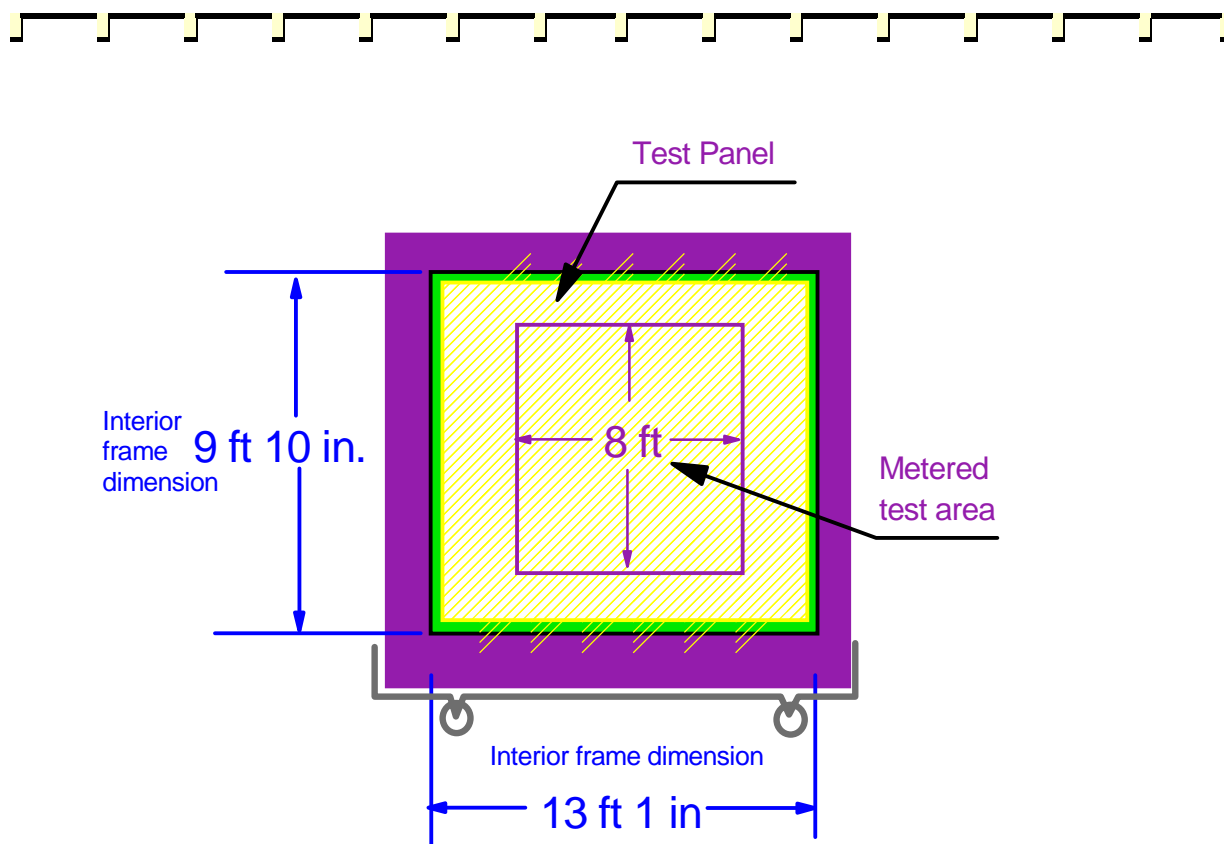


Figure 8 - Cross Section of RGHB Frame

In the center of the metering/guard chamber, a metering box is pressed against the test specimen assembly. The metering chamber is approximately 8-ft square by 1.3-ft deep. The walls of the metering chamber are constructed with 3-in. thick aged extruded polystyrene foam having an approximate thermal resistance of $15 \text{ hr}\cdot\text{ft}^2\text{°F}/\text{Btu}$ at 75° F . The walls of the metering box are reinforced with aluminum frames on the interior and exterior sides and are interconnected with fiberglass threaded rods. The edge of the metering chamber which contacts the test assembly is tapered to a thickness of 0.75-in. and a 0.5-in. square neoprene rubber gasket is affixed to this tapered edge. A baffle is mounted inside the metering box 6-in. from the exposed edge of the gasket. Behind the baffle, an array of eight fans and four electric resistance heaters is installed. These fans force air upward behind the baffle, through the resistance heaters, and downward through the airspace between the baffle and test assembly. The upper and lower rear corners of the metering box are tapered to minimize air impingement onto the metering box walls and to provide a smooth transition into the baffle space.

The guard box has four heaters and six fans that heat and circulate the air around the outside of the metering box. These heaters and fans are situated to achieve uniform temperatures throughout the guard box and not allow air to impinge directly onto the metering chamber.

A 96 junction (48 pair) differential thermopile is applied on the interior and exterior walls of the metering chamber to sense the temperature imbalance between the metering and guard chambers. Each thermopile junction is mounted in the center of one of the 48 equal areas into which the metering chamber is divided. The interior thermopile junction is mounted directly opposite the corresponding exterior junction. Additional arrays of temperature sensors are affixed to both the meter-side and climate-side surfaces of the foam panel surrounding the test specimen in the area covered by the metering

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chamber. All of the thermocouples that are attached to the surface of the foam are affixed with duct tape.

All temperature measurements were performed using Type T copper/constantan thermocouples calibrated to the special limits of error specified in ASTM E 230 [7]. All thermocouples were fabricated with No. 26 AWG (American Wire Gage) wire prepared from the same spool of wire.

Three differential pressure transducers were installed in the RGHB. Two of the transducers, P1 and P2, measure the pressure difference across the test assembly. These two transducers have different pressure ranges. The third transducer, P3, monitors the pressure difference between the metering and guard chambers.

In operation, the temperature of the climate chamber is set at the desired level. Separate programmable D.C. power supplies in conjunction with a temperature controller are used to energize and control the metering chamber heaters and fans. The power to the fans is adjusted to set the desired wind speed in the airspace between the baffle and the test wall assembly. An anemometer is used to monitor this wind speed. The power to the metering chamber heaters is adjusted to obtain the required metering chamber temperature. The output of the differential thermopile is used to energize the heaters in the guard chamber by using a differential temperature controller. By this technique, the temperature difference across the metering box walls is minimized, thereby permitting negligible heat leaks between the metering and guard chambers.

When an experiment requires air leakage, the blower connected to the metering chamber is energized, and the pressure difference across the test assembly is controlled by either adjusting the damper or the speed of the blower. The blower connected to the guard chamber is adjusted to minimize the pressure difference between the metering and guard chambers and thus the air leakage either through the metering chamber wall or past the seal between this chamber and the test assembly. Conditions are maintained until temperatures, heat flows, and pressure differences equilibrate. The heat flow generated by the metering chamber heaters is calculated from the voltage and current measurements taken from a precision shunt resistor. The energy dissipated by the metering chamber fans is metered with a precision resistor network. Once steady-state conditions have been achieved, the test period is continued until three successive four-hour periods produce results that vary non-monotonically by less than 1 percent. The data for each period is the average of one-minute scans for that period.

To verify the performance of the rotatable guarded hot box, a series of five verification experiments was performed on a homogeneous panel comprised of a 5-in. thick expanded polystyrene foam core faced on both sides with 0.12-in. high impact polystyrene sheet. In these experiments, the test conditions (temperatures of the metering and climate chambers) and the differential thermopile settings were varied. These experiments were performed to assess how closely we needed to maintain the null balance of the thermopile and to determine the precision of the RGHB. The metering chamber input heat flow is corrected for any losses through the metering chamber walls to determine the specimen heat flow. At mean temperatures of 50 and 75° F, the differential thermopile bias correction yields R-values that are within 0.05 and 0.02 hr•ft²°F/Btu of the average values, respectively. To obtain a 10 Btu/hr bias from the metering chamber requires a 1.5° F temperature imbalance across the metering chamber walls.

Specimens of the EPS foam used to fabricate the verification panel were tested at Oak Ridge National Laboratory. The testing was done to determine the thermal resistance of the specimens in accordance with ASTM C 518-98 [8]. ASHRAE Handbook of Fundamentals [9] value for the thermal resistance of the polystyrene sheet (0.36 hrft²°F/Btu) was used. Adding this thermal resistance to the R-value of the EPS foam, the R-value vs. temperature for the specimens of the verification panel was determined. These data were linearly regressed and compared to the data compiled in the RGHB.

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The test results generated between the two test apparatus were in agreement; all five of the ASTM C 236 (Standard replaced by C1363) [10][3] experiments performed in the RGHB are within $\pm 0.2\%$ of the ASTM C 518 results from the heat flow meter apparatus. Even if the thermal resistance of the polystyrene sheets estimate was in error by 50%, the results from the two procedures would still agree to within 1.1%. The need to estimate the R-value of the polystyrene sheets does not appreciably compromise the results that are presented.

Test Specimen

The specimen walls for both series of tests (phase I and phase II) were built and constructed at the NAHB Research Center laboratory. All test walls measured 96-in. x 96-in. Each assembled wall was positioned in the test frame such that the wall was centered both vertically and horizontally over the metering chamber opening. The area surrounding the test wall panel was filled with a thermally resistive foam insulation material, expanded polystyrene (EPS) and/or extruded polystyrene (XPS), to the same thickness as the tested wall. Excess polyisocyanurate was also used as fill material in the surround panel on some of the test walls. Since the surround is not part of the metered area, the type of insulation material used is inconsequential to the test results.

The R-13 batts used in the steel walls were Kraft paper faced while the R-19 batts were unfaced. To compensate for the lack of vapor barrier in the R-19 walls, polyethylene sheathing was applied between the insulation and the OSB. The drywall and OSB materials were fastened to the framing using standard No. 8 drywall and OSB screws, respectively. The screws were spaced at 6-in. intervals around the perimeter of the wall and at 12-in. intervals on the center studs.

Phase I Tests

A summary of the tested wall configuration is shown in Tables 7 and 8.

The fiberglass batts were carefully installed in the cavities to minimize gaps between the insulation and the stud/track interface. The insulation used on the 35S162-33 framed walls was Kraft paper faced and the seams were taped with masking tape to provide a tighter air barrier. The insulation used on the 55S162-33 framed walls was unfaced and a continuous polyethylene sheathing vapor barrier was used on the warm side. This barrier covered the entire surface of the test wall and was taped to prevent air leakage through the specimen. The Tuff-R[®] polyisocyanurate insulation used on the exterior of the OSB in tests 6 and 8 was attached with building adhesive and roofing nails. The roofing nails were primarily used to assure good thermal contact with the OSB surface and to secure the insulation while the adhesive was curing. The Tuff-R[®] exterior sheathing was also taped around the perimeter to prevent air leakage between the sheathing and the OSB. In the tests using the exterior sheathing, the thermocouple array on the exterior of the OSB was moved to the exterior of the sheathing and four additional thermocouples were installed between the Tuff-R[®] and the OSB.

Because of the increase in cavity depth after addition of the foam tape between framing and the exterior OSB sheathing, the R-13 fiberglass batt was tested at two thicknesses, 3.44 inch and 3.56 inch. It was assumed that the batt would expand into the slightly deeper cavity created by adding the foam tape. The foam tape was supplied in a roll and was approximately 0.25 inch thick by 1.15 inch wide. This made it difficult to determine the R-value with the ASTM C518 test. The thickness of the foam tape used in tests 2 and 4 was compressed to approximately 0.125 inches after the OSB was screwed into place, hence the 3.44 inch original cavity and the 3.56 inch expanded cavity. Because of the difficulty in measuring the R-value of the tape, comparable material was obtained in the form of 0.588-inch thick sheet. This material was tested by the ASTM C518 method at its original thickness and then was compressed as much as possible between two nominal 0.5-inch thick plywood squares and retested. The plywood was also tested

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separately. The foam R-value was then calculated by subtracting the value of the two layers of plywood from the total sandwich value. The results are inconclusive as to whether this method of backing out the R-value for the compressed foam is representative of the foam tape actually used in the tests. Tuff-R polyisocyanurate was used for both the additional sheathing and the rigid foam strips between the metal framing and exterior OSB in tests 5, 6, and 8. The expanded polystyrene (EPS) and extruded polystyrene (XPS) were both used for the surround panel fill material needed to make up the difference between the test wall area and the metering box cross sectional face area.

Because of the difficulty in maintaining a constant wall surface temperature across multiple test walls with varying surface and interior configurations, the controllers were adjusted to maintain constant air temperatures in the metering and climate chambers at 100°F and 50°F, respectively. Figure 9 shows the warm side (gypsum board) of one of the typical steel-framed walls positioned in the Rotatable Guarded Hot Box (RGHB) test frame. In addition to testing the steel-framed wall systems in the RGHB, samples were taken from each of the insulating materials used in the metered area of the test walls. These samples were tested in accordance with ASTM C 518-98, where the thermal resistance of each sample was measured. The specimens were subjected to mean temperatures of 50° F and 75° F matching the conditions tested in the RGHB

Table 7 – List of Phase I Tested Wall Assemblies ¹

Test No.	Test Name	Stud Size	Web Design		Sheathing			Modification
			Stud	Track	Interior	Exterior	Cavity Insulation	
1	W1T1	350S162-33	Solid	Solid	½” gypsum board	7/16-in. OSB	R-13	Base
2	W1T2	350S162-33	Solid	Solid	½” gypsum board	7/16-in. OSB ²	R-13	Foam tape between stud/track and OSB
3	W2T1	350S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB	R-13	Slit web design
4	W2T2	350S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB ²	R-13	Foam tape between stud/track and OSB
5	W2T3	350S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB ²	R-13	½” ISO on exterior side of OSB
6	W2T5	350S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB	R-13	½” ISO on exterior side of OSB
7	W3T1	550S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB	R-19	Base
8	W3T2	550S162-33	Slit	Slit	½” gypsum board	7/16-in. OSB	R-19	½” ISO on exterior side of OSB
9	W4T2	350S162-33	Slit	Solid	½” gypsum board	7/16-in. OSB	R-13	Slit stud w/solid track
10	W3T3	550S162-33	Slit	Solid	½” gypsum board	7/16-in. OSB	R-19	Slit stud w/solid track

¹ All wall sections are constructed with five studs and two tracks

² Foam or polyiso. tape installed on the interior surface between stud and drywall

Thermal Performance of Slit-Web Steel Wall Studs

Table 8 – Phase I Test Walls Configurations Estimated R-Values

Test No.	Test Name	Stud Size	Stud	Track	Cavity Insulation	Interior Sheathing-Value	Exterior Sheathing R-Value	Modification R-Value
1	W1T1	350S162-33	Solid	Solid	13	0.45	0.62	Base
2	W1T2	350S162-33	Solid	Solid	13	0.45	0.62	1.7
3	W2T1	550S162-33	Slit	Slit	13	0.45	0.62	-
4	W2T2	350S162-33	Slit	Slit	13	0.45	0.62	1.7
5	W2T3	350S162-33	Slit	Slit	13	0.45	0.62	3.5
6	W2T5	350S162-33	Slit	Slit	13	0.45	0.62	3.5
7	W3T1	350S162-33	Slit	Slit	19	0.45	0.62	Base
8	W3T2	550S162-33	Slit	Slit	19	0.45	0.62	3.5
9	W4T2	550S162-33	Slit	Solid	19	0.45	0.62	-
10	W3T3	350S162-33	Slit	Solid	13	0.45	0.62	-

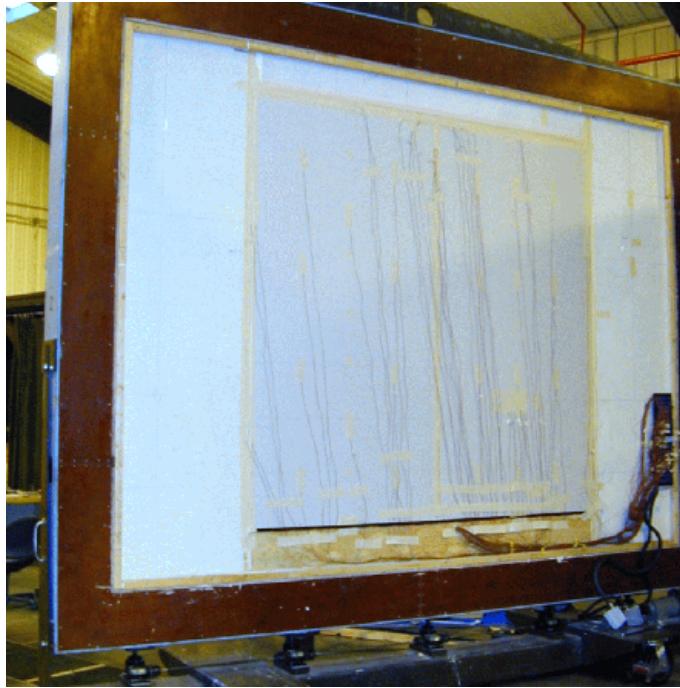


Figure 9 – Typical Test Wall in RGHB Frame

Arrays of thermocouples were used to measure the meter and climate chamber air temperatures. Table 9 provides a summary of the thermocouple locations for the test wall specimen. Figures 10, 11, 12, and 13 illustrate the locations of the thermocouples. Figure 14 shows a slit-web stud test wall assembly.

Thermal Performance of Slit-Web Steel Wall Studs



Table 9 – Location of Thermocouples Across Gypsum Surface (Phase I Tests)

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
1	6" right of stud center (outside)	11	2" left of stud center (inside)
2	2" right of stud center (outside)	12	1" left of stud center (inside)
3	1" right of stud center (outside)	13	Left stud edge (inside)
4	Right stud edge (outside)	14	Right stud edge (inside)
5	Left stud edge (outside)	15	1" right of stud center (inside)
6	1" left of stud center (outside)	16	2" right of stud center (inside)
7	2" left of stud center (outside)	17	6" right of stud center (inside)
8	6" left of stud center (outside)	18	Center of cavity left of stud
9	Center of stud (outside)	19	Center of cavity right of stud
10	6" left of stud center (inside)		

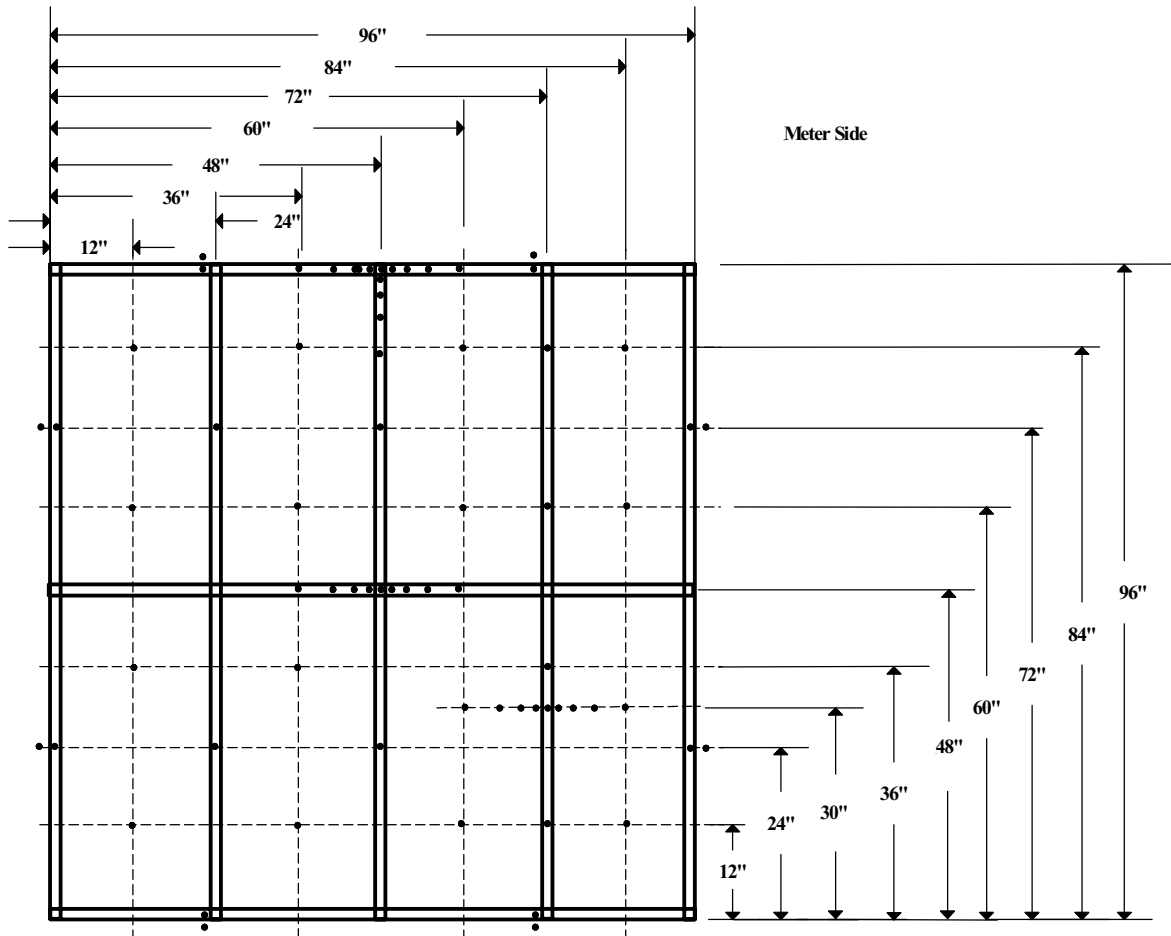


Figure 10 Wall Surface Thermocouple Detail

Thermal Performance of Slit-Web Steel Wall Studs

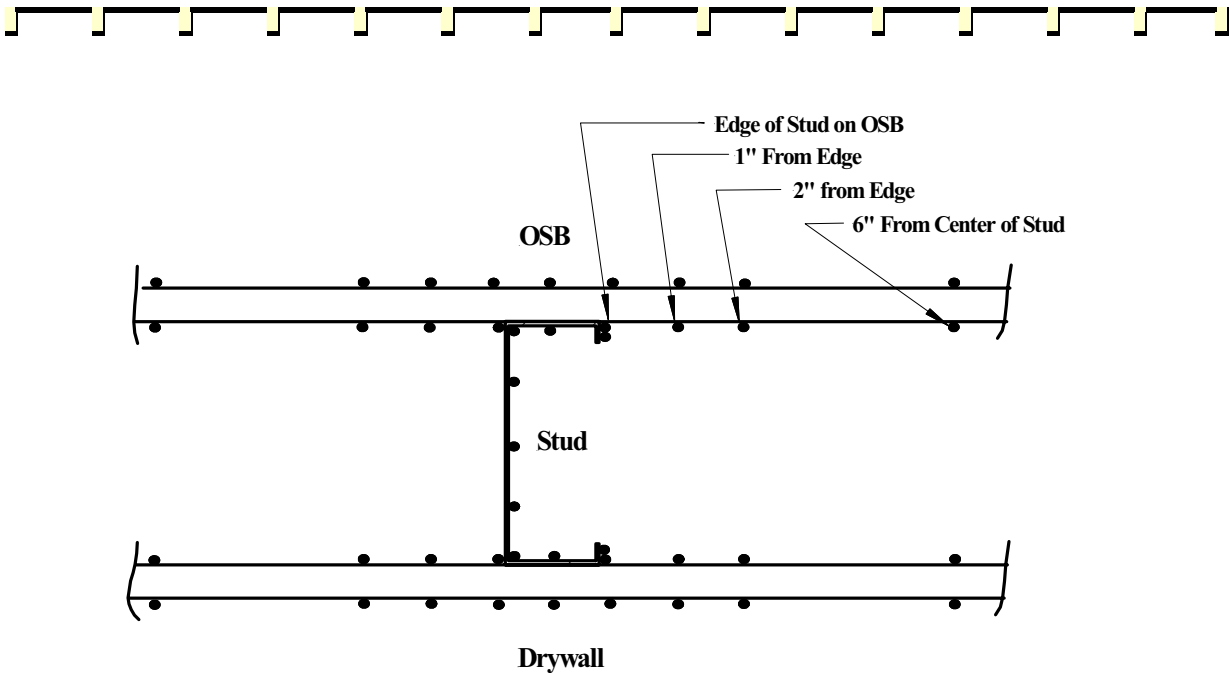


Figure 11 - Internal Stud TC Array Layout

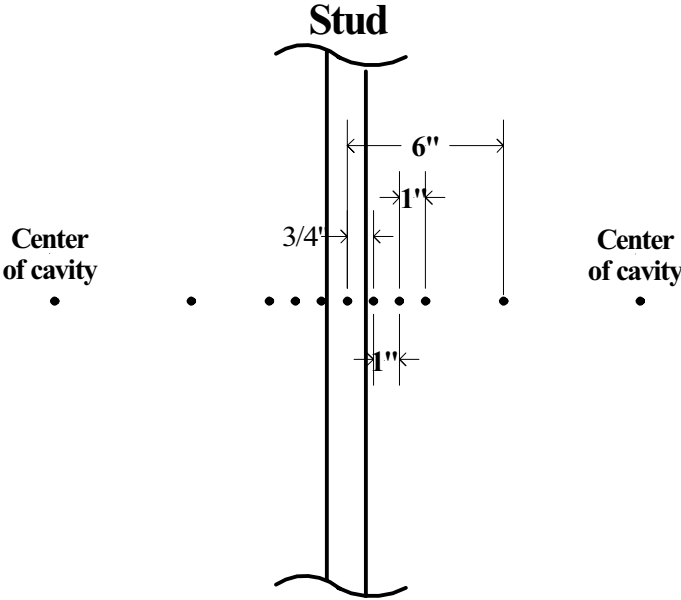


Figure 12 - Stud Array TC Layout

Thermal Performance of Slit-Web Steel Wall Studs

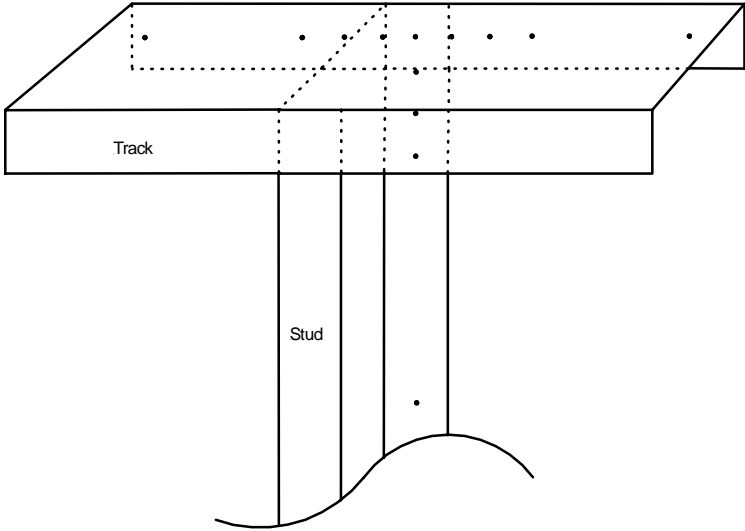


Figure 13 - Track TC Array



Figure 14 – Slit-Web Stud Wall Assembly

Thermal Performance of Slit-Web Steel Wall Studs



Phase II Tests

The slit-web stud was refined for this stage of testing. The refinement concentrated on enhancing the strength of the stud but maintaining its thermal characteristics. Details of the modified stud are shown in Figures 15 and 16. Figure 17 shows a photo of the prototype slit-web stud.

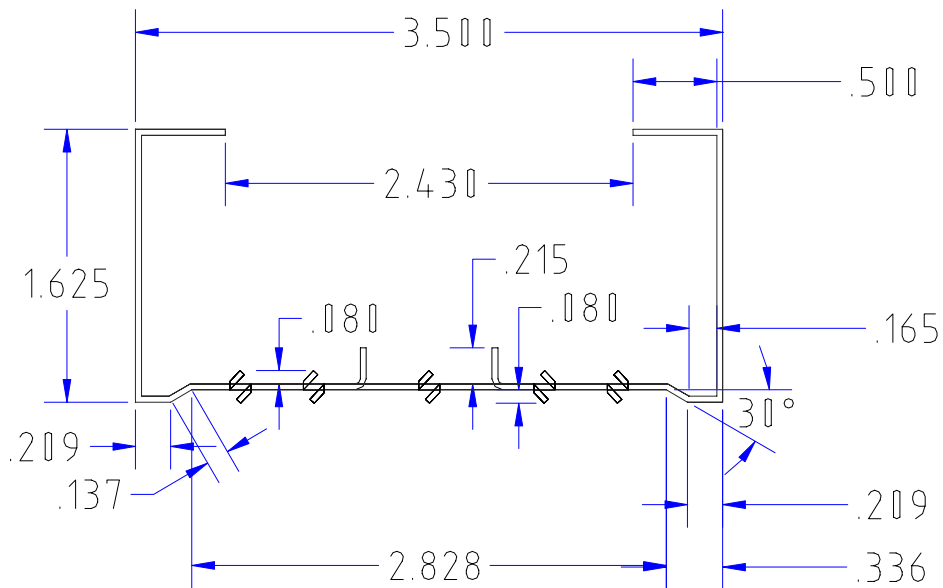
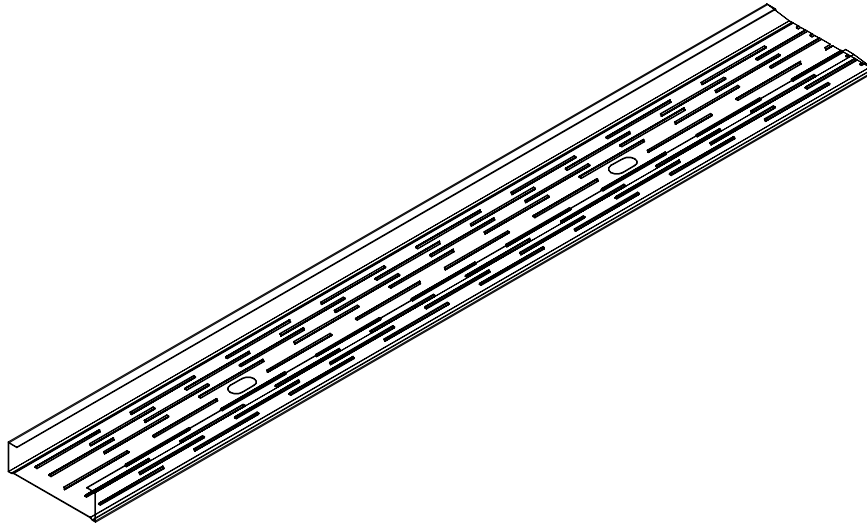


Figure 15 – Slit-Web Stud Configuration and Dimensions

Thermal Performance of Slit-Web Steel Wall Studs

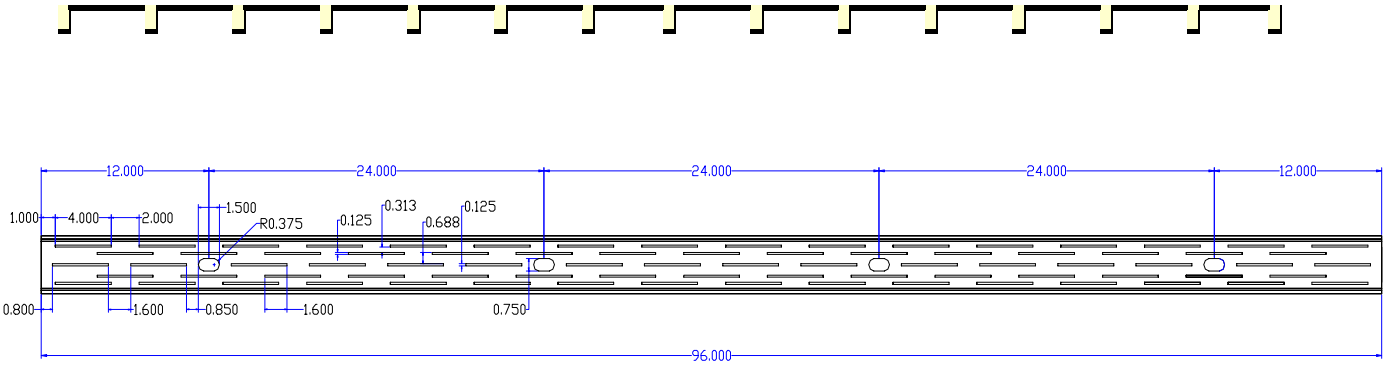


Figure 16 – Slit-Web Stud Configuration and Dimensions



Figure 17 – Prototype of Slit Web Stud

Thermal Performance of Slit-Web Steel Wall Studs



The test configurations consisted of 350S162033 (nominal 2 x 4) cold-formed steel-framed wall assemblies and 350S162-33 (nominal 2 x 4) slotted-stud walls, with the common characteristics of 0.5-in. thick gypsum board on the warm side, 7/16 in. thick oriented strand board (OSB) on the cold side, and full-width R-13 craft-faced fiberglass batt insulation in the cavities. Wall 2 was an exception and utilized a 1-1/2-in x 1-1/2-in x 33 mil galvanized steel strap placed horizontally across the studs and 1-in Tuff-R polyisocyanurate insulation in place of the 1/2-in OSB on the exterior side. Wall 6 also varied from the other walls in that the OSB was replaced with 33-mil galvanized steel sheet and the cavity insulation was unfaced R-15 batts.

Variations of the base walls tested included modified track/stud combinations and application of foam sheathing on the exterior OSB wall surface. Walls 2 through 4 and 6 through 7 utilized a split track design (L-headers), which consisted of removing a portion of the center track web to within 1-in of each bend (see Figure 18). The missing center portion provided a thermal break in the conduction path of the track. The top track for wall 5 used a modification of the split track design. This modification was applied to the top track only and consisted of a split track mounted to a nominal 2 x 4 wood stud. The bottom track was identical to the split tracks used in walls 2-4. The 2 x 4 used in this wall was part of the metered area, causing the metal studs to be 1-1/2-in shorter than the studs in the other walls. Wall 3, used in tests 6 and 7, was fabricated from solid web studs. Figure 17 shows a picture of one of the typical slit studs used in tests 1 through 5 and 8 through 10 and Figure 18 shows the split track design used in walls 2 through 4. Tables 10 and 11 list the tested walls with their respective tests and configurations.



Figure 18 – Typical Split Track (Angles)

Some of the wall assemblies (test samples) were damaged during shipment to ORNL, necessitating a visit to the BTC by NAHBRC personnel to evaluate the damage and to make the necessary repairs. The biggest concern with the damage was the collapsing of the slits in the slotted studs, thereby reducing the effectiveness of the conduction break in the path across the stud flange. Care was taken to assure that all slits were opened to their original spacing. After repair, the walls nonetheless retained some minor cosmetic damage consisting primarily of small dimples and dents. NAHBRC and BTC personnel concluded that these cosmetic blemishes would have negligible effect on the thermal performance of the framing.

Thermal Performance of Slit-Web Steel Wall Studs



Because of the difficulty in maintaining a constant wall surface temperature across multiple test walls with varying surface and interior configurations, the controllers were adjusted to maintain constant air temperatures in the metering and climate chambers at 100°F and 50°F, respectively. In addition to testing the steel-framed wall systems in the RGHB, samples were taken from each of the insulating materials used in the metered area of the test walls. These samples were tested in accordance with ASTM C 518-98, where the thermal resistance of each sample was measured. The specimens were subjected to mean temperatures of 50° F and 75° F matching the conditions tested in the RGHB.

Table 10 – Phase II Test Walls Configurations

Wall No.	Test No.	Test Name	Web Design		Sheathing		Modification
			Stud	Track	Interior	Exterior	
1	1	W1T1	Slit web	Solid	½” gypsum board	7/16-in. OSB	Base
1	2	W1T2	Slit web	Solid	½” gypsum board	7/16-in. OSB	0.5-in thick ISO foam
1	3	W1T3	Slit web	Solid	½” gypsum board	7/16-in. OSB	1.0-in thick ISO foam
1	4	W1T4	Slit web	Solid	½” gypsum board	7/16-in. OSB	2.0-in thick ISO foam
2	5	W2T5	Slit web	1½” x 1½” Angle	½” gypsum board	1-½” x 20 ga steel strap + 1.0-in thick ISO foam	-
3	6	W3T6	Solid web	1½” x 1½” Angle	½” gypsum board	7/16-in. OSB	Base
3	7	W3T7	Solid web	1½” x 1½” Angle	½” gypsum board	7/16-in. OSB	0.5-in thick ISO foam
4	8	W4T8	Slit web	1½” x 1½” Angle	½” gypsum board	7/16-in. OSB	Base
4	9	W4T9	Slit web	1½” x 1½” Angle	½” gypsum board	7/16-in. OSB	0.5-in thick ISO foam
5	10	W5T10	Slit web	2x4 wood plate	½” gypsum board	7/16-in. OSB	-
6	11	W6T11	Slit web	1½” x 1½” Angle	½” gypsum board	7/16-in. OSB	(R-15 FG cavity)
7	12	W7T12	Slit web	1½” x 1½” Angle	½” gypsum board	33-mil sheet steel	-

Thermal Performance of Slit-Web Steel Wall Studs

Table 11 – Phase II Test Walls Configurations Estimated R-Values

Wall No.	Test No.	Test Name	Stud	Track	Cavity Insulation	Interior Sheathing R-Value	Exterior Sheathing R-Value	Modification R-Value
1	1	W1T1	Slit web	Solid	13	0.45	0.62	Base
1	2	W1T2	Slit web	Solid	13	0.45	0.62	4.2
1	3	W1T3	Slit web	Solid	13	0.45	0.62	7.8
1	4	W1T4	Slit web	Solid	13	0.45	0.62	15
2	5	W2T5	Slit web	1½" x 1½" Angle	13	0.45	3.6	-
3	6	W3T6	Solid web	1½" x 1½" Angle	13	0.45	0.62	Base
3	7	W3T7	Solid web	1½" x 1½" Angle	13	0.45	0.62	4.2
4	8	W4T8	Slit web	1½" x 1½" Angle	13	0.45	0.62	Base
4	9	W4T9	Slit web	1½" x 1½" Angle	13	0.45	0.62	4.2
5	10	W5T10	Slit web	2x4 wood plate	13	0.45	0.62	-
6	11	W6T11	Slit web	1½" x 1½" Angle	15	0.45	0.62	-
7	12	W7T12	Slit web	1½" x 1½" Angle	13	0.45	0	-

Similar to Phase I tests, arrays of thermocouples were used to measure the meter and climate chamber air temperatures. Tables 12 through 16 provide a summary of the thermocouple locations for the test wall specimen (refer to Figures 10 through 14 for illustration of thermocouples location).

Table 12 – Location of Thermocouples Across Gypsum Surface (Phase 2 Tests)

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
G-H2	6" right of stud center (exterior)	M-E3	6" right of stud center (interior)
G-H3	2" right of stud edge (exterior)	M-E4	2" right of stud edge (interior)
G-H4	1" right of stud edge (exterior)	M-E5	1" right of stud edge (interior)
G-H5	Right stud edge (exterior)	M-E6	Right stud edge (interior)
G-H6	Center of stud (exterior)	M-F1	Left stud edge (interior)
M-J6	Left stud edge (exterior)	M-F2	1" left of stud edge (interior)
M-K6	1" left of stud edge (exterior)	M-F3	2" left of stud edge (interior)
G-L6	2" left of stud edge (exterior)	M-F4	6" left of stud center (interior)
G-M6	6" left of stud center (exterior)		

Thermal Performance of Slit-Web Steel Wall Studs



Table 13 – Location of Thermocouples Across OSB Surface (Phase 2 Tests)

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
B3	6" right of stud center (exterior)	A1	6" right of stud center (interior)
B4	2" right of stud edge (exterior)	A2	2" right of stud edge (interior)
B5	1" right of stud edge (exterior)	A3	1" right of stud edge (interior)
B6	Right stud edge (exterior)	A4	Right stud edge (interior)
E1	Center of stud (exterior)	M-G6	Center of stud (interior stud surface)
E2	Left stud edge (exterior)	A5	Left stud edge (interior)
E3	1" left of stud edge (exterior)	A6	1" left of stud edge (interior)
E4	2" left of stud edge (exterior)	B1	2" left of stud edge (interior)
E5	6" left of stud center (exterior)	B2	6" left of stud center (interior)

**Table 14 – Location of Thermocouples Across Steel Strap Surface (Phase 2 Tests)
Brace-OSB surface (inside) Looking from MC side**

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
A1	6" right of stud edge	B4	6" above Brace-OSB (stud)
A2	2" right of stud edge	B5	2" above Brace-OSB (stud)
A3	1" right of stud edge	B6	1" above Brace-OSB (stud)
A4	Right stud edge	E1	Top stud/Brace-OSB interface (stud)
A5	Brace/stud interface, inside stud	E2	Bottom stud/Brace-OSB interface (stud)
A6	Left stud edge	E3	1" below Brace-OSB (stud)
B1	1" left of stud edge	E4	2" below Brace-OSB (stud)
B2	2" left of stud edge	E5	6" below Brace-OSB (stud)
B3	6" left of stud edge		

**Table 15 – Location of Thermocouples Across Steel Strap Surface (Phase 2 Tests)
Brace-OSB surface outside**

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
F1	6" right of stud edge	G4	6" above Brace-OSB (stud)
F2	2" right of stud edge	G5	2" above Brace-OSB (stud)
F3	1" right of stud edge	G6	1" above Brace-OSB (stud)
F4	Right stud edge	H1	Top stud/Brace-OSB interface (stud)
F5	Brace/stud interface, outside stud	H2	Bottom stud/Brace-OSB interface (stud)
F6	Left stud edge	H3	1" below Brace-OSB (stud)
G1	1" left of stud edge	H4	2" below Brace-OSB (stud)
G2	2" left of stud edge	H5	6" below Brace-OSB (stud)
G3	6" left of stud edge		

Thermal Performance of Slit-Web Steel Wall Studs



Table 16 – Location of Thermocouples Across Interior Stud Surface (Phase 2 Tests)

Thermocouple No.	Thermocouple Location	Thermocouple No.	Thermocouple Location
M-F5	Back fold (gypsum side)	M-G4	Web, 1" from flange (OSB side)
M-F6	Flange, center (gypsum side)	M-G5	Web/flange intersection (OSB side)
M-G1	Web/flange intersection (gypsum side)	M-G6	Flange, center (OSB side)
M-G2	Web, 1" from flange (gypsum side)	M-H1	Back fold (OSB side)
M-G3	Web, center		

RESULTS

The results summarized in this section are taken from Oak Ridge National Lab reports [11] [12].

Phase I Tests

Table 17 presents the results of the ASTM C518 tests for the insulation and sheathing materials used for the wall specimens.

Table 17 – ASTM C518 Test Results (Phase I Tests)

Specimen	Thickness (in.)	Δt (°F)	T_{mean} (°F)	K (Btu-in/h.ft ² . °F)	R_{in} (hr.ft ² .°F/Btu)	R_{total} (hr.ft ² .°F/Btu)
R-13FG	3.56	50.1	50.0	0.2692	3.715	13.23
	3.56	50.0	75.0	0.2892	3.458	12.32
R-13FG	3.44	50.1	50.0	0.2642	3.785	13.04
	3.44	50.1	75.1	0.2857	3.50	12.06
R-19FG	5.5	60.1	50.0	0.2897	3.45	18.98
	5.5	50.1	75.1	0.3170	3.16	17.38
Tuff-R [®] Polyiso.	0.479	40.4	19.8	0.1258	7.949	3.81
	0.479	50.1	75.0	0.1389	7.199	3.45
Black Foam	0.588	50.1	50.0	0.2657	3.67	2.21
	0.588	50.1	75.1	0.2754	3.63	2.13
Black Foam plus Plywood	1.544	60.0	50.0	-	-	1.709
	1.544	50.0	75.0	-	-	1.660
Plywood	0.475	60.0	50.0	0.5945	1.682	0.799
	0.475	50.0	75.0	0.7047	1.419	0.674
Black Foam (Calc.)	0.1875	60.0	50.0	1.6892	0.5920	.111
		50.0	75.0	0.601	1.664	.312
XPS	2.06	60.0	50.0	0.1990	5.025	10.4
	2.06	50.0	75.0	0.2058	4.796	9.9
EPS	5.0	50.1	75.1	0.2528	3.96	19.80
	5.0	50.1	50.1	0.2362	4.23	21.15

Thermal Performance of Slit-Web Steel Wall Studs



Table 18 summarizes the calculated wall systems' R-values. The R-values were calculated based on the heat flow and temperature data that was measured during the tests. The temperatures and heat flows used were average for the time interval for each test after steady state had been achieved. When multiple temperature sensors are used to define a temperature, those sensors are averaged for each scan and then integrated over the time interval. The heading row in Table 16 lists the test designation number; e.g. W1T1 designates wall 1, test 1. The surface-to-surface R-values from table 16 are shown graphically in Figure 19. Stud array temperatures data are shown graphically in Figure 20.

Table 18 - Summary of Phase I Test Data and Calculations

Test No.	1	2	3	4	5	6	7	8	9	10
Test Name	W1T1	W1T2	W2T1	W2T2	W2T3	W2T5	W4T2	W3T1	W3T2	W3T3
Δt ¹	54.5	54.9	56.5	56.7	57.1	58.2	56.3	67.2	67.7	66.5
R_{wall} ²	8.1	8.2	10.2	10.4	11.1	13.9	9.5	13.4	17.3	11.4
$R_{ms\ air}$ ³	0.616	0.603	0.636	0.630	0.646	0.651	0.604	0.652	0.663	0.581
$R_{cs\ air}$ ⁴	0.218	0.197	0.192	0.175	0.158	0.180	0.236	0.279	0.329	0.245
$R_{u\ wall}$ ⁵	8.9	9.0	11.0	11.2	11.9	14.7	10.4	14.3	18.3	12.2
% Change in R_{wall} from Base	350S162-33 Base	1.2%	25.9%	28.4%	37.0%	71.6%	17.3%	550S162-33 Base	29.1%	-14.9%

¹ Δt is the temperature difference across sample wall.

² R_{wall} is the surface to surface R-value of the wall (hr.ft².°F/Btu).

³ $R_{ms\ air}$ is the meter side air film resistance (hr.ft².°F/Btu).

⁴ $R_{cs\ air}$ is the climate side air film resistance (hr.ft².°F/Btu).

⁵ $R_{u\ wall}$ is overall R-value of sample wall, $R_{ms\ air} + R_{wall} + R_{cs\ air}$ (hr.ft².°F/Btu).

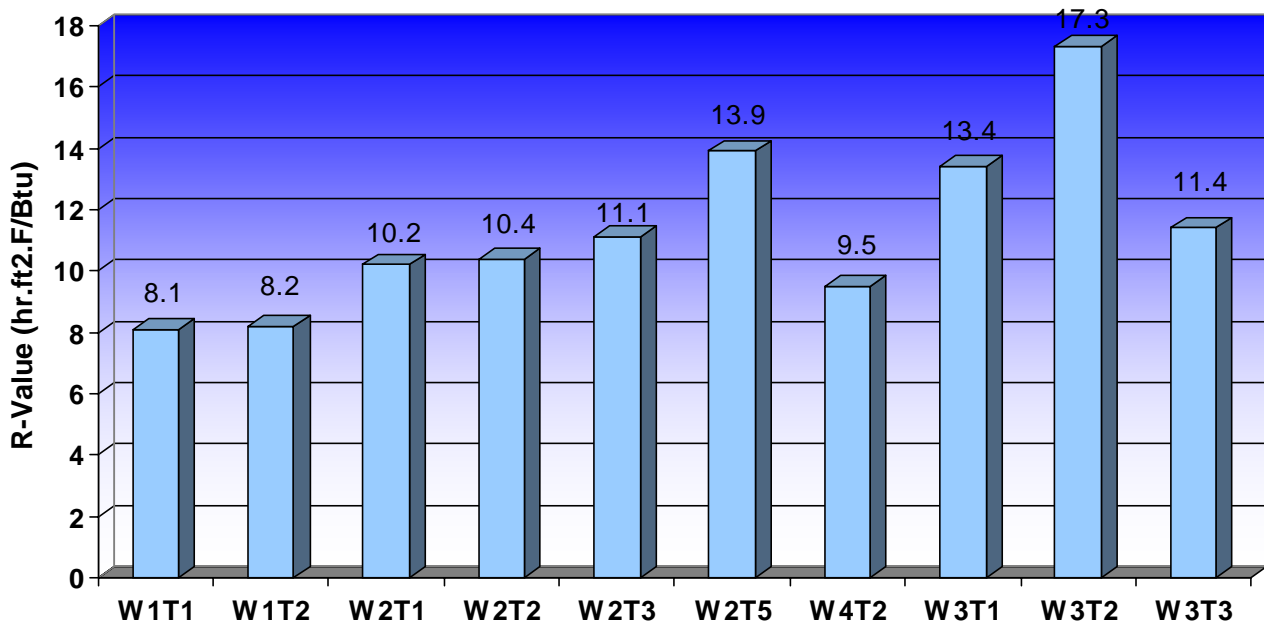


Figure 19 - Surface-to-Surface R-Values (Phase I)

Thermal Performance of Slit-Web Steel Wall Studs

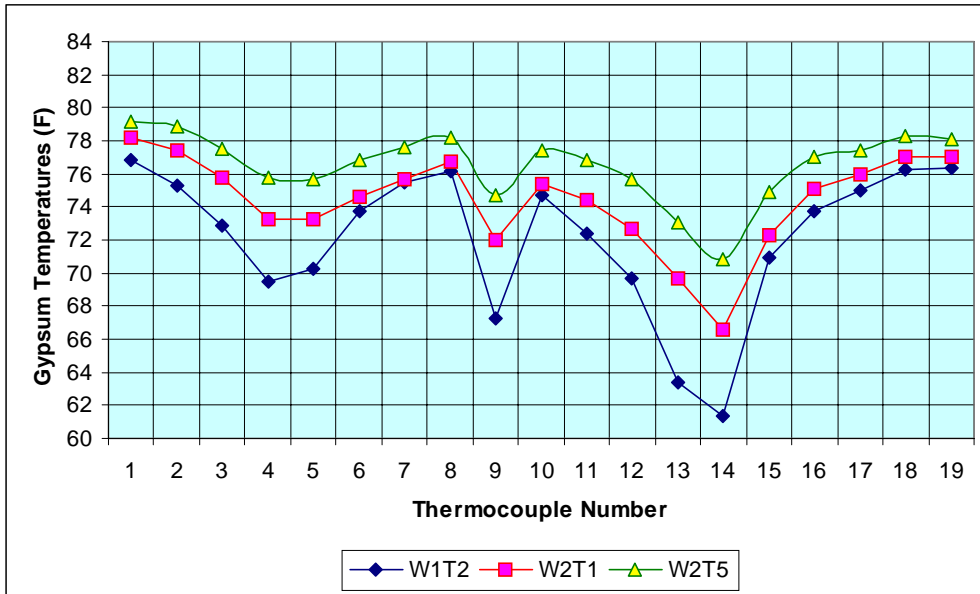


Figure 20 – Plot of Gypsum Surface Temperatures on 3-1/2” Steel Stud Walls

Phase II Tests

Table 19 presents the results of the ASTM C518 tests for the different materials used in the test specimens. Table 20 presents the R-values for each of the walls tested. The heading row in Table 18 lists the test designation number; e.g. W1T1 designates wall 1, test 1. Table

Table 21 was added as a continuation of Table 19 and shows data for two additional test runs at CC=20°F, MC=80°F made on wall 1, tests 1 and 4 (W1T1a and W1T4a). The primary purpose of these runs was to provide some additional data for comparison to Phase I test conditions.

The surface-to-surface R-values from Table 19 are shown graphically in Figure 21. Only the values for the standard chamber test conditions of MC= 100°F and CC= 50°F are shown. Stud array temperature data (refer to Table TC Locations in Tables 12 through 16) are shown graphically in Figures 22 and 23 with Figure 22 displaying the warm side (gypsum) data and Figure 23 displaying the cold side (OSB) data. These data are arranged in order to position the thermocouples in the chart as one would view from left to right if facing the gypsum board side of the wall. Figure 24 is a plot of the gypsum surface temperatures at the top track array.

Thermal Performance of Slit-Web Steel Wall Studs



Table 19 - ASTM C518 Test Results (Phase II Tests) ^{1,2}

Specimen	Thickness (in.)	Density (lb/ft ³)	T (°F)	T _{mean} (°F)	K (Btu-in/h.ft ² .°F)	R _{in} (hr.ft ² .°F/Btu)	R _{total} (hr.ft ² .°F/Btu)
R-13 FG Batt # 1	3.5	0.791	50.0	75.0	0.2964	3.37	11.81
			60.0	50.0	0.2707	3.69	12.93
R-13 FG Batt # 2	3.5	0.759	50.0	75.0	0.2926	3.42	11.96
			60.0	50.1	0.2672	3.74	13.10
R-13 FG Batt # 3	3.5	0.757	50.0	75.0	0.2835	3.53	12.35
			60.0	50.0	0.2628	3.81	13.32
R-15 FG Batt # 1	3.5	1.409	50.0	50.0	0.2224	4.50	15.74
			60.0	75.0	0.2377	4.21	14.72
R-15 FG Batt # 2	3.5	1.570	50.0	50.0	0.2185	4.58	16.02
			60.0	75.0	0.2328	4.30	15.03
R-15 FG Batt # 3	3.5	1.589	50.0	50.0	0.2183	4.58	16.03
			60.0	75.0	0.2329	4.29	15.03
Tuff-R® polyiso 1/2-in Thick	0.567	2.281	50.0	75.0	0.1493	6.70	3.80
			60.0	50.0	0.1398	7.16	4.06
Tuff-R® polyiso 1-in Thick	0.970	2.093	50.0	75.0	0.1457	6.86	6.66
			60.0	50.0	0.1356	7.37	7.16
Tuff-R® polyiso 2-in Thick	2.211	1.898	50.0	75.0	0.1446	6.92	15.29
			60.0	50.0	0.1338	7.47	16.52

Table 20 - Summary of Phase II Test Data and Calculations

Test No.	1	2	3	4	5	6	7	8	9	10	11	12
Test Name	W1T1	W1T2	W1T3	W1T4	W2T5	W3T6	W3T7	W4T8	W4T9	W5T10	W6T11	W7T12
Δt ¹	45.1	45.9	46.4	47.4	46.5	44.5	45.8	45.3	46.2	45.2	45.4	44.8
R _{wall} ²	9.4	12.9	15.1	20.3	16.3	8.5	12.2	10.4	14.0	10.5	10.9	9.7
R _{ms air} ³	0.698	0.701	0.710	0.708	0.700	0.683	0.687	0.706	0.703	0.752	0.720	0.729
R _{cs air} ⁴	0.342	0.451	0.435	0.407	0.456	0.355	0.418	0.353	0.456	0.350	0.329	0.447
R _{u wall} ⁵	10.4	14.1	16.2	21.5	17.4	9.6	13.3	11.4	15.1	11.6	12.0	10.9
% Change in R _{u wall} from Base (350S162-33 Solid web) ⁵	16.85	58.43	82.02	141.6	95.51	7.87	49.44	28.09	69.66	30.34	34.83	22.47

¹ Δt is the temperature difference across sample wall.

² R_{wall} is the surface to surface R-value of the wall (hr.ft².°F/Btu).

³ R_{ms air} is the meter side air film resistance (hr.ft².°F/Btu).

⁴ R_{cs air} is the climate side air film resistance (hr.ft².°F/Btu).

⁵ R_{u wall} is overall R-value of sample wall, R_{ms air} + R_{wall} + R_{cs air} (hr.ft².°F/Btu).

⁶ Base stud R-value of 8.9 is taken from Table 16.

Thermal Performance of Slit-Web Steel Wall Studs



**Table 21 - Summary of Phase II Test Data and Calculations
with CC=20° and MC=80° ^{1,2}**

Test Name	W1T1a	W1T1	W1T4a	W1T4
Δt ¹	54.0	45.1	56.9	47.4
R_{wall} ²	9.7	9.4	20.7	20.3
$R_{ms\ air}$ ³	0.702	0.698	0.656	0.708
$R_{cs\ air}$ ⁴	0.363	0.342	0.373	0.407
$R_{u\ wall}$ ⁵	10.7	10.4	21.8	21.5

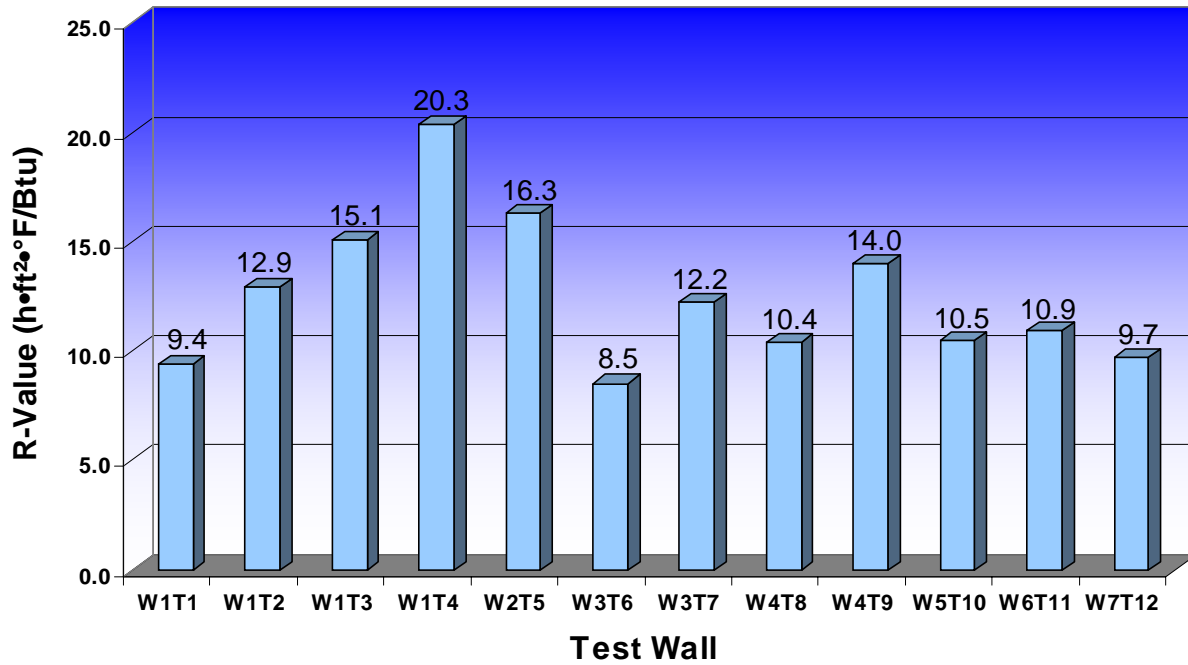


Figure 21 - Surface-to-Surface R-Values (Phase II)

Thermal Performance of Slit-Web Steel Wall Studs

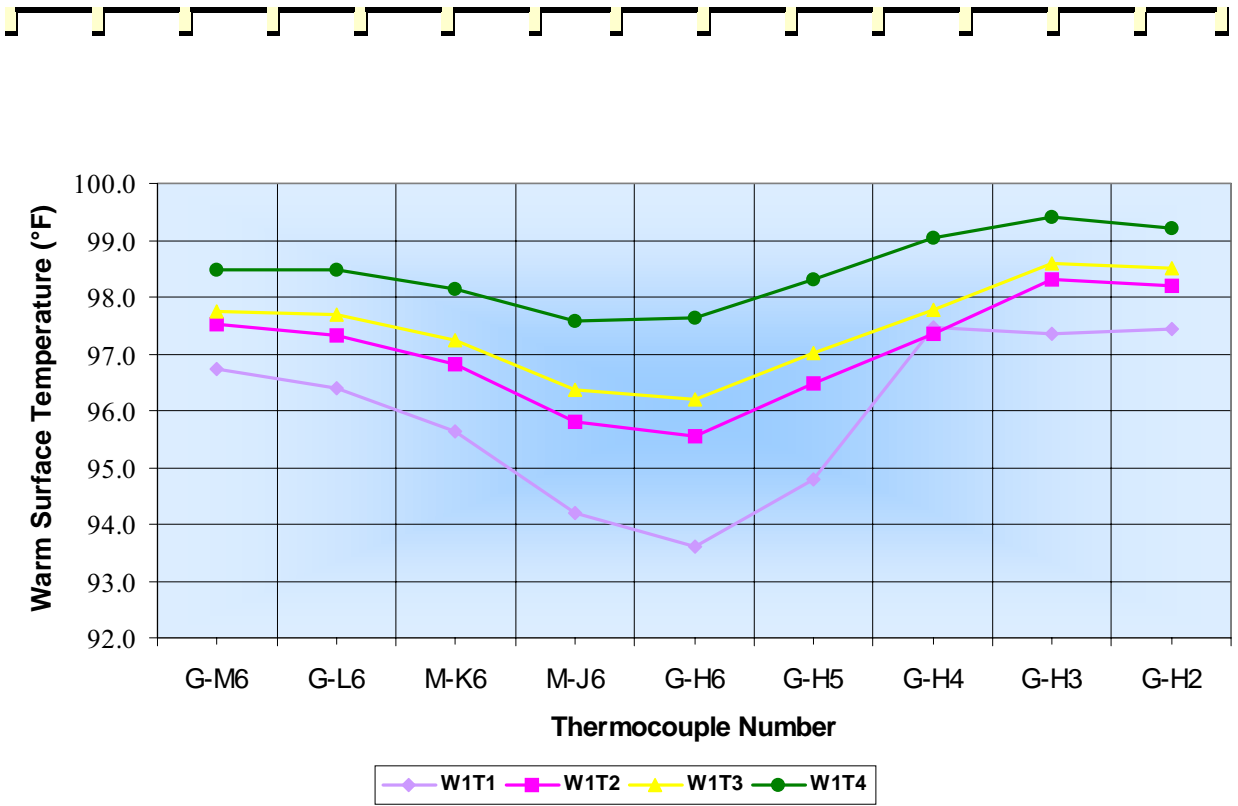


Figure 22 - Stud Array Temperatures at Gypsum Surface

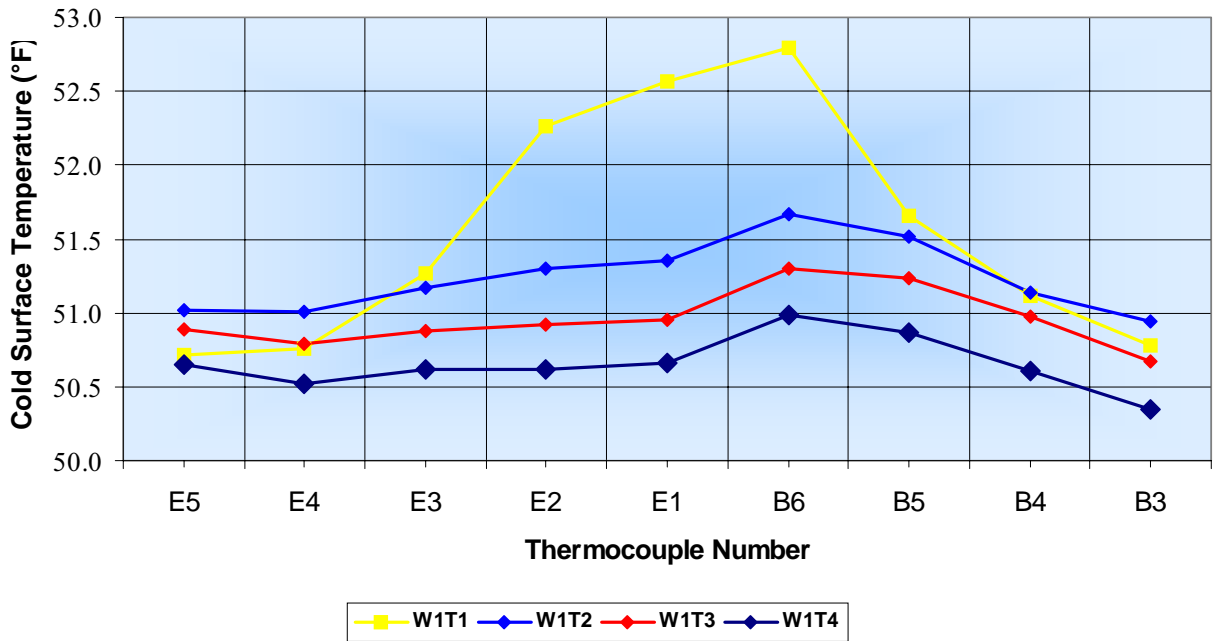


Figure 23 - Stud Array Temperatures at OSB Surface

Thermal Performance of Slit-Web Steel Wall Studs

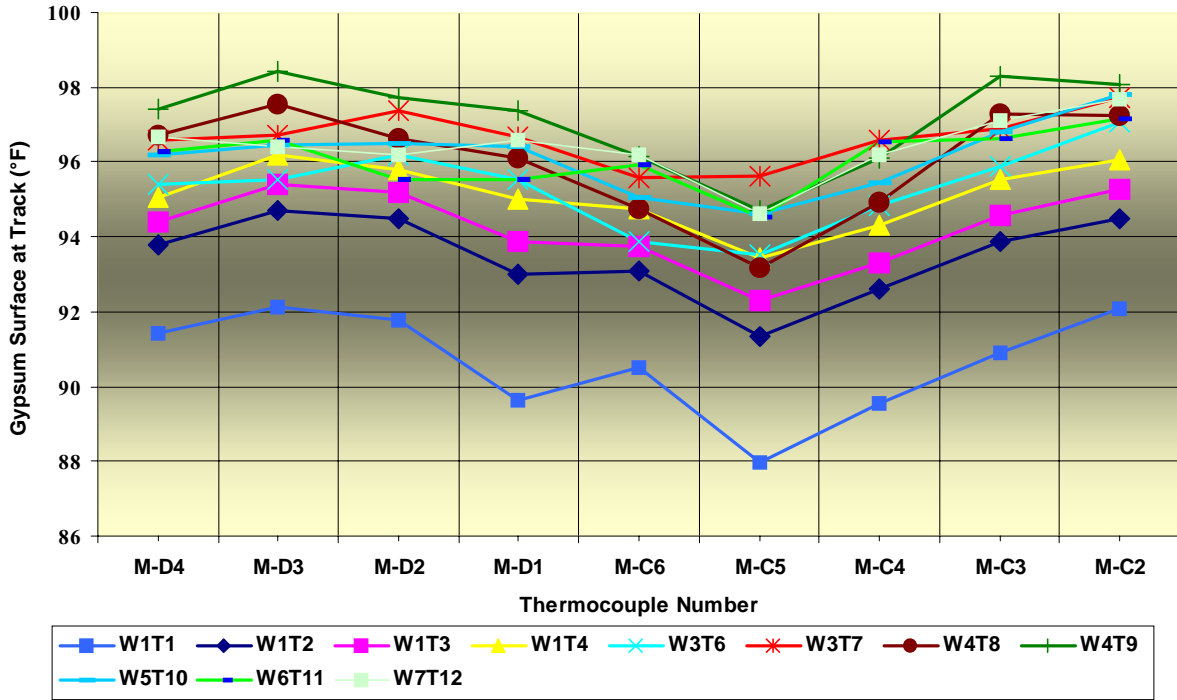


Figure 24 - Stud Array Temperatures at Gypsum Surface

Overall Results

Tables 22 and 23 compare the R-values for the slit-web studs and the solid-web studs with those of comparable wood studs (Table 22 only). It should be noted that the R-values for the solid-web studs were obtained from previous tests [1] that were conducted at a 50 °F mean temperature, R-11 cavity insulation, and polystyrene (XPS) exterior foam insulation while the tests conducted in this report were done at 75 °F mean temperature, R-13 cavity insulation and polyisocyanurate exterior foam insulation. The wood wall R-values shown in Table 22 were calculated using the Parallel-Path Flow Method [9].

Table 23 provides a summary comparison between the slit-web and solid-web steel studs with different cavity insulation.

Thermal Performance of Slit-Web Steel Wall Studs



Table 22 – Wall R-Value Comparison

Wall Parameter	Wall Detail	Slit Web Stud (R-Value)	Solid-Web Stud (R-Value)	Wood Stud (R-Value)
Cavity Insulation	R-13	10.4	8.9	12.7
Exterior Insulation	0			
Top Track/Plate	Solid Track			
Interior Drywall	½”			
Exterior Sheathing	7/16” OSB			
Cavity Insulation	R-13	14.1	11.4 ⁽¹⁾	16.3 ⁽⁴⁾
Exterior Insulation	½” Polyiso Foam			
Top Track/Plate	Solid Track			
Interior Drywall	½”			
Exterior Sheathing	7/16” OSB			
Cavity Insulation	R-13	16.2	13.9 ⁽²⁾	19.9 ⁽⁴⁾
Exterior Insulation	1” Polyiso Foam			
Top Track/Plate	Solid Track			
Interior Drywall	½”			
Exterior Sheathing	7/16” OSB			
Cavity Insulation	R-13	21.5	18.9 ⁽³⁾	28.7 ⁽⁴⁾
Exterior Insulation	2” Polyiso Foam			
Top Track/Plate	Solid Track			
Interior Drywall	½”			
Exterior Sheathing	7/16” OSB			
Cavity Insulation	R-13	17.4	-	12.2 ⁽⁴⁾
Exterior Insulation	1” Polyiso			
Top Track/Plate	150L150-33 Angles			
Interior Drywall	½”			
Exterior Sheathing	1-1/2” Steel Strap			
Cavity Insulation	R-13	11.6	-	12.7 ⁽⁴⁾
Exterior Insulation	0			
Top Track/Plate	2x4 Wood			
Interior Drywall	½”			
Exterior Sheathing	7/16” OSB			

¹ Value taken from [1] with R-11 cavity insulation, 362S162-43 studs and ½” XPS.

² Value taken from [1] with R-11 cavity insulation and 1” XPS.

³ Value taken from [1] with R-11 cavity insulation, 362S162-43 studs, and 2” XPS.

⁴ R-values are calculated using the ASHRAE Parallel-Path Flow Method.

Thermal Performance of Slit-Web Steel Wall Studs

Table 23 – Wall R-Value Comparison

Wall Parameter	Wall Detail	Slit Web Stud (R-Value)	Solid-Web Stud (R-Value)
Cavity Insulation	R-13	11.4	9.6
Exterior Insulation	0		
Top Track/Plate	150L150-33 Angles		
Interior Drywall	½”		
Exterior Sheathing	7/16” OSB		
Cavity Insulation	R-13	15.1	13.3
Exterior Insulation	½” Polyiso Foam		
Top Track/Plate	150L150-33 Angles		
Interior Drywall	½”		
Exterior Sheathing	7/16” OSB		
Cavity Insulation	R-15	12.0	-
Exterior Insulation	0		
Top Track/Plate	150L150-33 Angles		
Interior Drywall	½”		
Exterior Sheathing	7/16” OSB		
Cavity Insulation	R-13	10.9	-
Exterior Insulation	0		
Top Track/Plate	150L150-33 Angles		
Interior Drywall	½”		
Exterior Sheathing	33 mil sheet steel		
Cavity Insulation	R-19	12.2 ¹	-
Exterior Insulation	0		
Top Track/Plate	Solid		
Interior Drywall	½”		
Exterior Sheathing	7/16” OSB		

¹ R-value for 550S162-33 slit-web stud wall.

Table 24 - Impact of Cavity Insulation and Web Design

Wall Parameter	Slit Web Stud ⁽¹⁾		Solid-Web Stud ⁽¹⁾		Solid-Web Stud	
	Cavity Insulation	R-Value	Cavity Insulation	R-Value	Cavity Insulation	R-Value
Cavity Insulation	R-13	10.4	R-13	8.9	R-11	8.3 ⁽¹⁾
Exterior Insulation	None		None		None	
Interior Covering	½” drywall		½” drywall		½” drywall	
Exterior Sheathing	½” OSB		½” OSB		½” Plywood	
Cavity Insulation	R-13	14.1			R-11	11.4 ^(2,3)
Exterior Insulation	½” Polyiso. Foam				½” XPS	
Interior Covering	½” drywall				½” drywall	
Exterior Sheathing	½” OSB				½” Plywood	
Cavity Insulation	R-13	16.2			R-11	14.5 ^(2,3)
Exterior Insulation	1” Polyiso. Foam				1” XPS	
Interior Covering	½” drywall				½” drywall	
Exterior Sheathing	½” OSB				½” Plywood	

¹ Studs are 350S162-33, spaced at 24” on center.

² Studs are 362S162-33, spaced at 24” on center.

³ R-values are taken from reference 1.

Thermal Performance of Slit-Web Steel Wall Studs



CONCLUSION

Test results show the prototype slit web studs performed 17 percent better than the solid-web studs, giving an overall wall resitivity of R-10.4 for the 350S162-33 slit-web stud wall using R-13 fiberglass batts with exterior OSB sheathing and ½” interior drywall compared to an R-8.9 for solid web studs with the same configuration.

The best performing walls are those using slit web studs and angles (for top tracks), yielding a wall R-value of 11.4. Adding a thin layer (1/2”) of polyisocyanurate foam insulation on the exterior increases the wall R-value to 14.1; i.e., 28 percent improvement over solid web studs.

Tests also showed that increasing the cavity insulation from R-11 to R-15 does not significantly increase the total wall R-value (from R-11.4 to R-12). This result agrees with the findings of Bombino and Burnett [5].

Tests indicated that adding foam tape on the solid web stud flanges provides very little additional R-value (R-Value increases from 8.1 to 8.2, see Figure 19). A slit-web stud with wood top plate produces an R-value (R-11.6) that is equivalent to that of a slit-web stud with double angle (R-11.4) top track (see Tables 22 and 23). Tests also showed that the overall wall R-value for walls with exterior sheathing could be estimated by adding the exterior insulation R-value to the base slit-web stud R-value.

Thermal Performance of Slit-Web Steel Wall Studs



REFERENCES

- [1] “*Thermal Design Guide for Exterior Walls.*” American Iron and Steel Institute (AISI) Publication RG-9405. Washington DC, January 1995.
- [2] Energy Design Update “*Weighing Thermal Design Strategies for Steel-Framed Homes (Part 1).*” Volume 19, No. 12. Surry NH. December 1999.
- [3] ASTM C1363-97 “*Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus.*” American Society for Testing and Materials (ASTM), West Conshohocken, PA. 1997.
- [4] Elhajj, Nader, “*Structural Testing of Slit-Web Steel Studs.*” Report Prepared for the American Iron and Steel Institute (AISI), Steel Framing Alliance, and the U.S. Department of Energy by the NAHB Research Center. Upper Marlboro, MD. 2002.
- [5] Bombino, R, and Burnett, E. “*Design Issues with Steel-stud-framed Wall Systems.*” Pennsylvania Housing research Center (PHRC) Report No. A58. 1999.
- [6] Errera, J. L “*Tests of Wall Panels and Components for Mode 1 Residential Steel Framing Systems.*” Bethlehem Steel Corporation Report No. 72-7-3. Bethlehem Pennsylvania. August 1974.
- [7] ASTM E230-98e1 “*Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples.*” American Society for Testing and Materials (ASTM), West Conshohocken, PA. 1998.
- [8] ASTM C518-98 “*Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.*” American Society for Testing and Materials (ASTM), West Conshohocken, PA. 1998.
- [9] ASHRAE Fundamentals Handbook. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta GA. 2001.
- [10] ASTM C236-89 (1993) e1 “*Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box.*” American Society for Testing and Materials (ASTM), West Conshohocken, PA. 1998.
- [11] “*An Evaluation of the Steady-State Thermal Performance of Thermally Efficient Steel Frame Wall System (Phase I).*” Report prepared by the Oak Ridge National Laboratory for the NAHB Research Center. January 2000.
- [12] “*An Evaluation of the Steady-State Thermal Performance of Thermally Efficient Steel Frame Wall System (Phase II).*” Report prepared by the Oak Ridge National Laboratory for the NAHB Research Center. July 2002.

Thermal Performance of Slit-Web Steel Wall Studs



APPENDIX A
List of Thermal Solution Options

Option Name: Snap-Cap™ and Flat-Cap™

Option Number: 1

Option Design Category:

Frame Insulating Fitting	X
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: Extruded polystyrene foam, C-shaped profile that press-fits to end of metal stud, insulating and extending 2X4 stud to a 2X6 dimension (Snap-Cap™) or flat foam fitting with adhesive back for attachment to end of stud (Flat-Cap™). Various configurations are available. A somewhat similar design tested in New Zealand⁴ consists of a PVC clip that attaches to the flange of the C to form a thermal break with about a 5 mm air gap.

Estimated Additional R-Value: R-7 additional for use of a 2” Snap-Cap on 4” stud against use of 6” stud with no cap.

Estimated Marginal Material Cost (\$/ft²): \$0.075/ft² (15 cents per lineal foot) for 2” thick insulation for 1.625” flange studs (Available in 4’ and 8’ lengths).

Estimated Marginal Labor Cost (\$/ft²): Low. Manufacturer says that combined material and labor costs are “50% less than for the insulating sheathing assembly” that uses 1” polystyrene outside of plywood.

Additional Advantages/Liabilities: Does not provide capability for significant transfer of sheer loading between wallboard and frame. However, it is predicted that this should not impact use of the product (on the inside flange). Reported that the ½” SnapCap has been used on the outside flange without structural problems, but larger (#10) screws needed for securing sheathing. Product may not resolve through-foam screw driving issues. May be some interference when cross bracing used.

State of Commercialization: Available commercially under the above name, licensed design by ORNL (patent pending), produced by US Building Technology, Inc., Natick, MA. 508-652-0055, www.usbt.com.

References:

1. U.S. Building Technology, Inc. manufacturer’s literature
2. “Report on the Thermal Resistance of Two Framed Walls with Insulated Cavities”, Holometrix, Inc. for U.S. Building Technology, Inc., Report #UBT-1, February 1998.
3. Environmental Building News, 5:4

Option Name: Astec® Ceramic Insulating Coatings

Option Number: 2

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	X
Stud Modification	
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: Ceramic coating that can be applied to steel stud flanges by manufacturer with high insulating value.

Estimated Additional R-Value: Low

Estimated Marginal Material Cost (\$/ft²): \$0.50 per sq.ft. of covered surface

Estimated Marginal Labor Cost (\$/ft²): None

Additional Advantages/Liabilities: Does not significantly inhibit transfer of sheer loading between wall and frame.

State of Commercialization: Available commercially under the above name, through Astec Insulating Coatings Corporation, Binghamton, NY, 800-223-8494.

References: Manufacturer literature

Additional Comments: Claimed high durability, adhesion. Apparently used on space shuttle nose cone.

Option Name: Insulated Track
Option Number: 3

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural Insulating Panels	
Other:	

Description: A frame system uses two parallel tracks formed from a single sheet, holding two parallel metal 15/8” studs which are separated by an air gap, except at the point of track contact.

Estimated Additional R-Value: High

Estimated Marginal Material Cost (\$/ft²): Absolute cost for 16-gauge frame for 4” studs is \$1.90 per foot. For 6” studs is \$2.28 per foot.

Estimated Marginal Labor Cost (\$/ft²): Moderate-High

Additional Advantages/Liabilities: Unknown shear properties – less stiff than a single stud structure? How is connection to track made at inside flanges of studs - clips?

State of Commercialization: Commercially available. Patent is being sought by California Expanded Metal Products Company – Application #29/078,683, filed Oct. 30, 1997.

References: Manufacturer literature. Contact Wes Westmoreland, Tom Porter, Richard Poliquin at California Expanded Metal Products Company, City of Industry, CA (Bassett, CA), 626-369-3564.

Additional Comments:

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Slit Web
Option Number: 4

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: A metal stud is modified for lower heat transfer by the introduction of slots cut out of the web. The “Knauf” slit web uses a stud 3/16” X 31/2” with 3/4” between slots, rows 3/16” apart. Slit web using triangular cutouts (see ORNL refs) have base of about 2” along length of channel, with height of cutout (into stud depth) varying according to configuration. The slotted channel by the Swedish Firm Lindab Profil AB has 8 rows of slots along the length of the 150mm deep channel, staggered and spaced 10 mm apart.

Estimated Additional R-Value: 2.0 – 2.6 for triangular cutout studs, depending on configuration.

Estimated Marginal Material Cost (\$/ft²): None-Low⁹

Estimated Marginal Labor Cost (\$/ft²): None

Additional Advantages/Liabilities: Potential structural liabilities – [McDermott] and [Ife] show in lateral load tests that wall sections using 18 gauge slit web channels (parallel rows of narrow slits) are about 8%-13% weaker than those using solid webbed channels.

State of Commercialization: Delta stud patent, initially defended by Thermasteel, bought by South African company Macsteel.

References:

1. Kosny, J., et al, “Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?” ASHRAE Transactions, 1997, V.103, Part 1.
2. McDermott, J.F., “Load Tests on Steel-Stud Walls”, U.S. Steel Research Laboratory.
3. “ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood,” Energy Design Update, March 1997.
4. Ife, L., “The Performance of Cold-Formed Steel Products in Housing.” The Steel Company of Canada, Ltd., 1975.
5. Letter report to Tom Porter of CEMCO Steel from Engineer Richard Palmer regarding thermal analyses of various slit web stud configurations.
6. Blomberg, Thomas, “Heat Conduction in Two and Three Dimensions; Computer Modelling of Building Physics Applications”, Lund University, Sweden, Report #TVBH-1006, May 1994.
7. Crise, D.J., “Thermal Performance of Walls Framed with Steel Studs with Slit Webs”, U.S. Steel Research Laboratory, 48.019-005(3), November 15, 1972.
8. Ratliff, G.D., et al, “Thermal and Structural Behavior of Walls Made with Steel Studs with Slit Webs,” U.S. Steel Research Laboratory, 57.019-052(5), December 7, 1971.
9. Conversation with Don Moody, Residential Steel Partnership, 202-452-7100, by NAHB staff R. Johnson, August 27, 1998.
10. Nieminen, J., et al, “Design and Thermal Performance of Insulated Sheet Metal Structures,” Nordic Steel Construction Conference, 1995.

Summary Evaluation: If marginal manufacturing costs can be held down, this configuration has a high market potential for warmer regions.

Option Name: Rigid Foam Sheathing
Option Number: 5

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Use of rigid foam sheathing on the exterior of plywood sheathing, including expanded polystyrene and extruded polystyrene.

Estimated Additional R-Value: R-5 per inch for extruded polystyrene, R-4 for expanded polystyrene.

Estimated Marginal Material Cost (\$/ft²): Extruded polystyrene: \$0.45/ft². Based on \$7 per 2x8 sheet of 1" EPS and \$0.20 per section for roofing nails. Expanded polystyrene: \$0.23/ft² for expanded polystyrene.

Estimated Marginal Labor Cost (\$/ft²): \$0.08/ft².

Additional Advantages/Liabilities: Requires furring strips for attachment of siding. Screw attachment complexities possible (e.g., screws upsetting inside insulation). Difficult to attach metal lath to foam for stucco houses.

State of Commercialization: Standard practice.

References:

1. Kosny, J., et al, "Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?" ASHRAE Transactions, 1997, V.103, Part 1.
2. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, Nov 1996.
3. "ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood," Energy Design Update, March 1997.

Option Name: Ridged Flange
Option Number: 6

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural/Insulating Panels	
Other:	

Description: Metal stud shape is modified to form two ridges on the flanges that provide essentially line contact with sheathing versus plane contact on standard flanges. Although the channel configuration is modified, it remains an extruded shape.

Estimated Additional R-Value: 1.13, using 1/2" ridges on 6" studs.

Estimated Marginal Material Cost (\$/ft²): Low

Estimated Marginal Labor Cost (\$/ft²): None - Low

Additional Advantages/Liabilities: Involves driving screws across 1/2" air gap for mounting board. May compromise structural properties.

State of Commercialization: n/a

References:

1. "LeRoy Landers' Marvelous Steel Stud", Energy Design Update, page 5, June, 1995.
2. U.S. Patent #5,592,796, Thermally-improved Metallic Framing Assembly," January 14, 1997.
3. Kosny, J., et al, "Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?", ASHRAE Transactions, 1997, V.103, Part 1.
4. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, Nov 1996.
5. "ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood," Energy Design Update, March 1997.

Option Name: Dimpled Flange

Option Number: 7

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural/Insulating Panels	
Other:	

Description: The flange of the metal is modified with extruded (rectangular, hemispherical, u-shaped or other) dimples to reduce the flange surface area in contact with the sheathing. Although the channel configuration is modified, it remains an extruded shape.

Estimated Additional R-Value: About 0.61, using 0.1" square dimples on 4" studs, 16 gauge steel.

Estimated Marginal Material Cost (\$/ft²): Low

Estimated Marginal Labor Cost (\$/ft²): None - Low

Additional Advantages/Liabilities: May not involve any compromise in buildability or structural integrity.

State of Commercialization: Reported to have been on market by July 1994, Angeles Metal Systems, Los Angeles, CA.

References:

1. Kosny, J., et al, "Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?" ASHRAE Transactions, 1997, V.103, Part 1.
2. "Thermally Efficient (?) Steel Studs," Energy Design Update, April, 1994.
3. U.S. Patent #5,285,615, "Thermal Metallic Building Stud"
4. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, November 1996.

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Circular Slot Web

Option Number: 8

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural/Insulating Panels	
Other:	

Description: Modification to the stud is in the form of circular holes in web to reduce surface area and thus reduce heat transfer across the web. Holes are punched with a tab left to increase member strength. Although the channel configuration is modified, it remains an extruded shape.

Estimated Additional R-Value: About 1.5 – 2.5. Use of two rows of staggered 1.25-inch holes located 0.5 inches from the flanges reduces the effective U-value of the web section by about 47%.

Estimated Marginal Material Cost (\$/ft²): Low

Estimated Marginal Labor Cost (\$/ft²): Negative to Low

Additional Advantages/Liabilities: Potential for higher structural integrity (because of the use of circular slots with “burrs”). Precut holes save electrical and plumbing labor. No significant changes to current construction techniques.

State of Commercialization: New design concept.

References: Machaj, E. and Zakrzewski, A., “Energy Considerations in Low-Rise Steel Buildings,” Fifth Specialty Conference, 1978.

Option Name: Furring Strips
Option Number: 9

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural/Insulating Panels	
Other:	

Description: Spacers in the form of horizontal furring strips are mounted on the metal studs to isolate the exterior sheathing from the studs. Furring strips may be of plastic, metal, or wood. Air space is filled with fiberglass batt insulation or sprayed-in-place insulation.

Estimated Additional R-Value: 1.0 for use of 1”x 2” wood furring strips and R-11 fiberglass insulation. 2.0 with same configuration, except using foil-faced insulation instead of paper-faced¹. Estimated R-5 for use of polyurethane foam, R-7 with polyisocyanurate, R-3.5 with sprayed-in cellulose.

Estimated Marginal Material Cost (\$/ft²): Moderate

Estimated Marginal Labor Cost (\$/ft²): Moderate

Additional Advantages/Liabilities: Plastic furring strips in common use. Eliminates fastener contact with stud. Enhances acoustic properties.

State of Commercialization: Horizontal furring strips in common use. Advanced Framing Systems, Monroe, GA, 800-633-8600, installs sheathing and siding attached to horizontal “hat” sections.

References:

1. Kosny, J., et al, “Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?” ASHRAE Transactions, 1997, V.103, Part 1.
2. “Thermal Performance of Cold Formed Steel Framing Assemblies”, Christian and Kosny, BETEC Symposium, Nov 1996.
3. “ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood,” Energy Design Update, March 1997.
4. Kosny, J. et al, “Thermal Performance of ‘Energy-Efficiency’ Metal Stud Wall Systems,” ASHRAE Building Envelopes Conference VI, December, 1995.
5. “Steel Framing: Thermally Challenged?” Journal of Light Construction, March, 1994.

Additional Comments: May be corrosion issues when using some sprayed-in cellulose techniques with steel framing. Use of sprayed-in cellulose may require galvanized fasteners.

Option Name: EESI-Stud
Option Number: 10

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	X
Structural/Insulating Panels	
Other:	

Description: EESI-Stud (“Energy Efficient Stud Interchangeable”) consists of two rows of triangular metal beams are connected with either wood or metal connectors. Currently, only metal connectors are available commercially.

Estimated Additional R-Value: $R-3.7^2$

Estimated Marginal Material Cost (\$/ft² wall area): \$0.025/ft², based on \$0.40 additional per 2”x4”x8” steel stud⁵. Additional cost is additional freight from southern to northern California. AISI Cost Reduction Field Study results cites an increased cost of \$0.18 per linear foot for material only, equivalent to \$1.44 per stud.

Estimated Marginal Labor Cost (\$/ft²): \$0.08/ft² including materials cost.

Additional Advantages/Liabilities: Noted that these are the only steel-framed wall configurations on the market that meet California’s Title-24 energy efficiency codes without the use of expanded polystyrene insulation. May be difficulties in implementing corners and other details because of unusual shape.

State of Commercialization: Produced by Tri-Chord Systems of El Cajon, CA.

References:

1. EESI-Stud mfg. literature, Earth Sense web site, www.nccn.net.
2. Jon Leber and Soheil Loghmanpour, Technical memo, “Cost and Thermal Properties of Steel Framed Wall Systems,” California Energy Commission, April 7, 1995.
3. “ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood,” Energy Design Update, March 1997.
4. U.S Patent #5,692,353
5. Conversation with John Oakie, Earth Sense Steel Framing Systems, Grass Valley, CA, 530-274-0650, by NAHBRC staff R. Johnson, August 28, 1998.

Option Name: Structural Insulation – Cellulosic Low Density Board Panels

Option Number: 11a

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Foam, composite or other structural insulating sheathing for use on the exterior to avoid the necessity of installation of both plywood and a separate insulation layer.

Estimated Additional R-Value: Refer to following table for currently available values.

Thickness	1/2"		1"	
	Regular density	High density	Regular density	High density
R-value	1.39	1.3	2.78	2.5

Estimated Marginal Labor Cost¹: Based on data from the NAHB Research Center report, foam requires 0.0042 hours/ft². Using 98 RS Means Cost data, the loaded labor rate for a laborer is \$22.95 and \$31.70 for a carpenter. Assuming a two-man installation crew, the average loaded labor cost is \$27.33. The estimated labor cost is:

- \$0.08 per ft² surface area,
- \$1.28 for a typical section, or
- \$0.64 per lineal foot of wall.

State of Commercialization: Celotex regular and high-density fiberboard is available as a roof insulation from Celotex Company, Tampa, FL, 800-235-6329.

References:

1. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, Nov, 1996.
2. "ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood," Energy Design Update, March, 1997.
3. Celotex company literature.

Additional Comments:

Product is currently used as a roofing insulation. Since fiberboard can result in premature failure if exposed to water, dew point calculations are necessary determine suitability. Structural strength also needs to be examined.

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- 1/2" plywood sheathing
- 3 1/2" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- 1/2" gypsum board

Option Name: Structural Insulation – Corner Board Structural (CBS) Sheathing
Option Number: 11b

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Foam, composite or other structural insulating sheathing for use on the exterior to avoid the necessity of installation of both plywood and a separate insulation layer.

Estimated Additional R-Value: Refer to following table for currently available values.

Thickness	½”	5/8”	¾”	7/8”	1”
R-value	3.6	4.5	5.4	6.3	7.2

Estimated Marginal Material Cost¹: Estimated sheathing costs were provided by Celotex of \$0.26/ft² for ½” thick foam and \$0.36/ft² for 1” thick foam. Installation of this product requires the application of construction adhesive to develop the wall shear strength. Field studies documented an average adhesive consumption of 1-1/2 tubes per 4’ x 8’ sheet, or 0.047 tubes per square foot. Mechanical fasteners are used to secure the material until the adhesive has dried. The product requires the facers to be undamaged to achieve the maximum shear strength. Field studies reported success using stiff plastic washers to protect the facer. Under a standard fastener pattern of 6”/12” there are 1.69 washers/ ft². The washer cost is \$0.10/ft².

Estimated Marginal Labor Cost¹: Based on data from the NAHB Research Center report, foam requires 0.0042 hours/ft². Using 98 RS Means Cost data, the loaded labor rate for a laborer is \$22.95 and \$31.70 for a carpenter. Assuming a two-man installation crew, the average loaded labor cost is \$27.33. The estimated labor cost is:

- \$0.08 per ft² surface area,
- \$1.28 for a typical section, or
- \$0.64 per lineal foot of wall.

State of Commercialization: CBS board available from Celotex Corporation, Tampa FL.

References:

1. *Thermal Performance of Cold Formed Steel Framing Assemblies*, Christian and Kosny, BETEC Symposium, November 1996.
2. *ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood*, Energy Design Update, March, 1997.
3. *Celotex CBS Insulating Sheathing Field Evaluations*, NAHB Research Center, January 1997.

¹ Values assume clear wall R values for 2’ x 8’ (16 ft²) section with 3 1/2” x 1 1/2” studs 24” O.C., unless otherwise noted; cost is to builder.

Option Name: Structural Insulation – Foam insulation with structural metal facer
Option Number: 11c

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Polyisocyanurate foam with a structural aluminum facer. The aluminum facer is available in the following thicknesses,

Estimated Additional R-Value: Refer to following table for currently available values.

Thickness	½”	1”	1-1/2”
R-value	3.6	7.2	10.8

Estimated Marginal Material Cost: This product’s wholesale cost is:

	Thickness (mils)	\$/ft ² surface area	\$/2’X8’ section	\$/ Lineal foot of wall
½” thick foam	1.25	\$0.44	\$7.04	\$3.52
1” thick foam	1.25	\$0.62	\$9.92	\$4.96
1-1/2” thick foam	1.25	\$0.81	\$12.96	\$6.48
½” thick foam	4	\$0.61	\$9.76	\$4.88
1” thick foam	4	\$0.83	\$13.28	\$6.64
1-1/2” thick foam	4	\$1.05	\$16.80	\$8.40
½” thick foam	16.5	\$1.86	\$29.76	\$14.88
1” thick foam	16.5	\$2.05	\$32.80	\$16.40
1-1/2” thick foam	16.5	\$2.25	\$36.00	\$18.00

Estimated Marginal Labor Cost: Based on data from the NAHB Research Center report, foam requires 0.0042 hours/ft². Using 1998 RS Means Cost data, the loaded labor rate for a laborer is \$22.95 and \$31.70 for a carpenter. Assuming a two-man installation crew, the average loaded labor cost is \$27.33. The estimated labor cost is:

\$0.08 per ft² surface area, or
 \$0.64 per lineal foot of wall.

Estimated Marginal Installation Cost: The estimated installation cost is:

	Thickness (mils)	\$/ft ² surface area	\$/2'X8' section	\$/ Lineal foot of wall
½" thick foam	1.25	\$0.52	\$8.32	\$4.16
1" thick foam	1.25	\$0.70	\$11.20	\$5.60
1-1/2" thick foam	1.25	\$0.89	\$14.24	\$7.12
½" thick foam	4	\$0.69	\$11.04	\$5.52
1" thick foam	4	\$0.91	\$14.56	\$7.28
1-1/2" thick foam	4	\$1.13	\$18.08	\$9.04
½" thick foam	16.5	\$1.94	\$31.04	\$15.52
1" thick foam	16.5	\$2.13	\$34.08	\$17.04
1-1/2" thick foam	16.5	\$2.33	\$37.28	\$18.64

State of Commercialization: Thermax Plus is available from Celotex Corporation, Tampa, FL. Foam bonded to steel HTI Inc, Ninden NV, 702-782-8800, fax 702-782-2070.

References:

1. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, November 1996.
2. "ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood," Energy Design Update, March 1997.
3. Celotex company literature.
4. *Alternative Framing Materials in Residential Construction: Three Case Studies*, NAHB Research Center, U.S. Department of Housing and Urban development (HUD), July 1994.

Option Name: E'NRG'Y 2 Nailboard Structural Insulation
Option Number: 11f

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: A polyisocyanurate foam core bonded on one side to a 7/16" thick OSB panel and on the other side to a fiberglass facer.

Estimated Additional R-Value: R-6.6

Estimated Marginal Material Cost (\$/ft²): Board cost is about \$25 for a 4X8 sheet in a 1.5" thickness (minimum available). (\$79 per 100ft²)¹. Cost of plywood sheathing is eliminated.

Estimated Marginal Labor Cost (\$/ft²): Low - None

Additional Advantages/Liabilities:

State of Commercialization: Commercially available through NRG Barriers, 15 Lund Road, Saco, ME, 800-343-1285.

References:

1. Conversation with NRG representative and mfg. literature, October 6, 1998.
2. Energy Source Directory, Iris Communications, 1994, 503-484-9353.

Additional Notes:

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Thermal Tape
Option Number: 12

Option Design Category:

Frame Insulating Fitting	X
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	
Other:	

Description: Thermal break in the form of an adhesive tape. A 5/16" thick silicone foam tape, 3/4" wide, was tested by NAHB (Ref. 1). The product manufactured by Shadwell Company will be 1-1/2" wide with a thickness between 1/8" and 1/4". May also use thin rigid foam strips instead of tape.

Estimated Additional R-Value: 0.5 (Ref. 2) - 1.0+ (Ref. 3). The Shadwell product has not been tested at this time but estimates of R-value for tape only range from 3.7 to 4.7 for 1/4" thick tape.

Estimated Marginal Material Cost¹: The estimated material cost is \$0.15 per linear foot. This translates to:

\$0.11 per ft² surface area, (application on one side of wall only), or
\$0.90 per lineal foot of wall.

Estimated Marginal Labor Cost: The cost to install this product is minimal. Assuming one minute to install one wall section 8' x 8', the product takes 0.0021 hrs/ft². The estimated labor cost is:

\$0.058 per ft² surface area, or
\$0.47 per lineal foot of wall.

Estimated Marginal Installation Cost: The estimated installation cost is:

\$0.17 per ft² surface area, or
\$1.37 per lineal foot of wall.

Additional Advantages/Liabilities: Foam tape tested by NAHB became compressed to as thin as 1/8" near fasteners. May be increased tendency toward screw pops or bulging on drywall. Will not interfere with cross-bracing.

State of Commercialization: Tape, currently in prototyping, will be available from Shadwell Company, Inc., Chagrin Falls, OH, 800-494-4148.

References:

1. *Field Test of the Thermal Performance of a Residential Steel-Framed Wall with Insulating Sheathing*, NAHB Research Center, 1993.
2. *Energy Design Update*, page 9, March, 1995.
3. Notes from Thermal Workshop for Steel Framing, March 8, 1996, NAHB Research Center.
4. *Thermal Tests of Roof/Ceiling Assemblies*, NAHB Research Center, May 1996.

Summary Evaluation: This product is promising as one component to optimize the performance of steel-framed construction. Proprietary ceiling insulation testing by the NAHB Research Center revealed great

potential when tape was applied to the interior or warm side flange.

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Super Therm Insulating Coating

Option Number: 13

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	X
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	
Other:	

Description: Insulating and reflective coating.

Estimated Additional R-Value: n/a

Estimated Marginal Material Cost: Per manufacturer’s literature, product covers 100 ft²/gallon per coat. Per ORNL study, product covers 60 ft²/gallon per coat; research shows one coat optimal. Using ORNL data, cost is reported as \$166.95 per 5-gallon container. The estimated material cost is:

\$0.56 per ft² surface area, or
\$4.48 per lineal foot of wall.

Estimated Marginal Labor Cost: Estimate from ORNL report is 48 man-hours to remove debris and loose gravel, remove ponded water, and apply product. The total roof surface is 5,725 ft². Assuming incidental tasks occupied half the time, it took 24 man-hours to apply product, therefore the product requires 0.0042 hours/ft². Using 98 RS Means Cost data, the loaded labor rate for a laborer is \$22.95 and \$31.70 for a carpenter. Assuming a two-man installation crew, the average loaded labor cost is \$27.33. The estimated labor cost is:

\$0.11 per ft² surface area, or
\$0.88 per lineal foot of wall.

Estimated Marginal Installation Cost: The estimated installation cost is:

\$0.67 per ft² surface area, or
\$5.36 per lineal foot of wall.

Additional Advantages/Liabilities: Energy savings from this product are primarily achieved by reflecting radiation away from the structure. There is limited R-value, and limited use except as an exterior surface finish. This product may have usefulness when optimizing roof/ceiling assemblies.

State of Commercialization: ThermShield International, Shreveport LA, 318-425-1934

References:

1. *International Energy Report*, (Mfg. Literature), March 31, 1997.
2. “Fantasy Coatings to Be Tested By Oak Ridge”, *Energy Design Update*, December, 1995.
3. *Radiation Control Coatings Installed on Federal Buildings at Tyndall Air Force Base, Volume 1 - Pre-Coating Monitoring and Fresh Coating Results*, Oak Ridge National Laboratory, ORNL/CON-439/V1, February 1997.
4. *Radiation Control Coatings Installed on Federal Buildings at Tyndall Air Force Base, Volume 2 - Long-Term Monitoring and Modeling*, Oak Ridge National Laboratory, ORNL/CON-439/V2, June 1998.

Additional Comments: Product demonstrated approximately a 50% decrease in heat flux through the roof, based on ORNL testing in Florida. Products strength will be in mechanical cooling-dominated climates.

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Metal/Foam Laminate Sheathing

Option Number: 14

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Polyisocyanurate foam with a structural aluminum facer. The aluminum facer is available in the following thicknesses,

Estimated Additional R-Value: Refer to following table for currently available values.

Thickness	½"	1"	1-1/2"
R-value	3.6	7.2	10.8

Estimated Marginal Material Cost: This product's wholesale cost is:

	thickness (mils)	\$/ft ² surface area	\$/2'x8' section	\$/ lineal foot of wall
½" thick foam	1.25	\$0.44	\$7.04	\$3.52
1" thick foam	1.25	\$0.62	\$9.92	\$4.96
1-1/2" thick foam	1.25	\$0.81	\$12.96	\$6.48
½" thick foam	4	\$0.61	\$9.76	\$4.88
1" thick foam	4	\$0.83	\$13.28	\$6.64
1-1/2" thick foam	4	\$1.05	\$16.80	\$8.40
½" thick foam	16.5	\$1.86	\$29.76	\$14.88
1" thick foam	16.5	\$2.05	\$32.80	\$16.40
1-1/2" thick foam	16.5	\$2.25	\$36.00	\$18.00

Estimated Marginal Labor Cost: Based on data from the NAHB Research Center report, foam requires 0.0042 hours/ft². Using 98 RS Means Cost data, the loaded labor rate for a laborer is \$22.95 and \$31.70 for a carpenter. Assuming a two-man installation crew, the average loaded labor cost is \$27.33. The estimated labor cost is:

\$0.08 per ft² surface area, or
\$0.64 per lineal foot of wall.

Estimated Marginal Installation Cost: The estimated installation cost is:

	thickness (mils)	\$/ft ² surface area	\$/2'X8'section	\$/ Lineal foot of wall
½" thick foam	1.25	\$0.52	\$8.32	\$4.16
1" thick foam	1.25	\$0.70	\$11.20	\$5.60
1-1/2" thick foam	1.25	\$0.89	\$14.24	\$7.12
½" thick foam	4	\$0.69	\$11.04	\$5.52
1" thick foam	4	\$0.91	\$14.56	\$7.28
1-1/2" thick foam	4	\$1.13	\$18.08	\$9.04
½" thick foam	16.5	\$1.94	\$31.04	\$15.52
1" thick foam	16.5	\$2.13	\$34.08	\$17.04
1-1/2" thick foam	16.5	\$2.33	\$37.28	\$18.64

State of Commercialization: Thermax Plus is available from Celotex Corporation, Tampa, FL. Foam bonded to steel: HTI Inc, Ninden NV, 702-782-8800, fax 702-782-2070.

References:

1. "Thermal Performance of Cold Formed Steel Framing Assemblies", Christian and Kosny, BETEC Symposium, Nov, 1996.
2. "ORNL Concludes Steel Framing Can Perform as Well as, or Even Better than, Wood," Energy Design Update, March, 1997.
3. Celotex company literature.
4. *Alternative Framing Materials in Residential Construction: Three Case Studies*, NAHB Research Center, U.S. Department of Housing and Urban Development (HUD). July 1994.

Additional Comments:

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Foil-Backed Board

Option Number: 15

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	
Other: Radiating/Conducting Coating	X

Description: Foil-backed wall board helps stop radiation losses through wall. Foil backing may also help better distribute temperature along the interior of the wall, mitigating ghosting.

Estimated Additional R-Value:

Estimated Marginal Material Cost (\$/ft²):

Estimated Marginal Labor Cost (\$/ft²): None

State of Commercialization: Commercially available.

References: Crise, D.J., “Thermal Performance of Walls Framed with Steel Studs with Slit Webs”, November 15, 1972.

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Offset Framing
Option Number: 16

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural Insulating Panels	
Other:	

Description: Framing members are smaller in web dimension than the wall section, and are alternately placed against the inside and outside walls, offsetting them and eliminating the thermal bridging.

Estimated Additional R-Value: About R-3.0 for studs spaced 24" O.C.¹

Estimated Marginal Material Cost (\$/ft²): Moderate.

Estimated Marginal Labor Cost (\$/ft²): n/a

Additional Advantages/Liabilities: Potential structural liabilities.

State of Commercialization:

References:

1. "Energy Basics" (EZFRAME User's Manual), California Energy Commission, CABEC Annual Conference, July 29-30, 1994.

Additional Comments: EZFRAME User's Manual evaluates R-value on wall section with studs 4' on center on each side of wall, which is not according to code. In practice, the number of studs would increase by at least 50% (16" to 12" on center).

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Broken Web
Option Number: 17

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: Various configurations in which a thermal break is established by using multiple metal frame pieces that partially nest inside one another, separated by rigid insulation, to form the stud.

Estimated Additional R-Value: R-4.5 for Simulation 18 in ORNL study¹

Estimated Marginal Material Cost (\$/ft²): n/a

Estimated Marginal Labor Cost (\$/ft²): n/a

Additional Advantages/Liabilities: Potential structural liabilities.

References:

1. Kosny, J., et al, "Thermal Breaking Systems for Metal Stud Walls – Can Metal Stud Walls Perform as Well as Wood Stud Walls?", Oak Ridge National Laboratory, ASHRAE Transactions 1997, V.103, Pt.1.
2. U.S. Patent #5,617,695, "Thermally Insulated Composite Frame Member and Method for the Manufacture Thereof", April 8, 1997.

Additional Comments:

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Hybrid Stud
Option Number: 18

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	X
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: Wall stud is composed of metal and insulating components, with portions in contact with inside and outside walls consisting of small channels, held together by structural insulating materials.

Estimated Additional R-Value: R-2.5 to R-3.0 for FSEC design⁴

Estimated Marginal Material Cost (\$/ft²): Medium - High

Estimated Marginal Labor Cost (\$/ft²): Medium - High

Additional Advantages/Liabilities: Potential structural liabilities. Higher cost.

State of Commercialization: Steel-Stix wood and steel studs available.

References:

1. U.S. Patent #5,609,006, "Wall Stud", March 11, 1997.
2. U.S. Patent #5,713,176, "Combination Metal and Composite Stud," Feb. 3, 1998.
3. Kosny, J. et al, Oak Ridge National Laboratory, Rudd, A., Florida Solar Energy Center, "Whole Wall Rating/Label for Florida Solar Energy Center Combined Wood/Metal Wall System; Steady State Thermal Analysis", September 10, 1997.
4. Conversation with Armin Rudd, Florida Solar Energy Center, September, 1998.

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Panel System with Rigid Insulation
Option Number: 19

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural Insulating Panels	
Other:	

Description: A panelized wall is constructed of plywood/OSB, rigid insulation and metal (usually channel) shapes. In some cases, use of sheathing is reduced because of the structural value of the rigid insulation.

Estimated Additional R-Value: HTI 3 1/2" panel has nominal R-value of 14.7, an additional R of 6.8. Thermastructure panel has R-value of 14, equivalent to an additional R-6.1. Thermotech 7 1/4" panels are estimated at a resistance of R-27.

Estimated Marginal Material Cost (\$/ft²): Thermastructure wall panels priced at \$1.65/square foot⁴. Thermotech panels about \$4 per square foot, FOB Cleveland.³ Assuming a baseline of \$1.60 per ft² mat & labor for standard steel frame plus insulation (ref. NAHB and Means Residential), this is 5 cents per ft² premium for the Thermastructure wall panels, if sheathing is required. Manufacturer claims sheathing not required, which would mean a cost savings is realized vs. "stick-built" steel stud walls.

Estimated Marginal Labor Cost (\$/ft²): n/a

Additional Advantages/Liabilities:

State of Commercialization: System available through Thermastructure, Ltd, Radford, VA, 540-633-5000. Prefab channel & EPS foam panel available through HTI, Inc., 702-782-8800. Techbuilt Systems, Inc. produces the Thermotech 21 wall, Cleveland, OH, 216-621-4340.

References:

1. U.S. Patent #5,638,651, "Interlocking Panel Building System", June 17, 1997.
2. Johannesson, F., et al, "A New Structural System Made of Sheet Metal Profiles Supported by Blocks of Expanded Polystyrene," Nordic Steel Construction Conference, 1995.
3. Energy Design Update. July 1995.
4. Thermastructure, Ltd representative, 540-633-5000, September 25, 1998.

Option Name: Foamed Cement Insulated Metal Framing System
Option Number: 20

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural Insulating Panels	
Other:	

Description: Wall framing system is composed of metal framing system and wall built up from stacks of foamed cement blocks or from 2'X8' panels

Estimated Additional R-Value: R-0.5 to R-2²

Estimated Marginal Material Cost (\$/ft²): Absolute cost of \$32 per 2'X8' panel, 6" thick.

Estimated Marginal Labor Cost (\$/ft²): n/a

State of Commercialization: Patent cited assigned to Insu-Form Incorporated of Cathedral City, CA, (760) 324-0216, and Omega Transworld, Ltd. of New Kensington, PA, 800-541-1575. Contact Mr. Hacker in Seattle, WA @ 253-848-5291 or 253-840-3982.

References:

1. U.S. Patent #5,596,860, "Foamed Cement Insulated Metal Frame Building System", January 28, 1997.
2. Letter from John Hacker to Soheil Loghmanpour, CEC, citing results of U=0.10 for 8'X8' wall section test by Quality Testing Lab of Everett, WA, 206-259-6799.

Additional Notes: Density of foamed cement about 20 lbs/ft³, R-value of 13.0. Steel stud 20-gauge. Hacker notes heating costs for a 3200 ft² home in Washington of \$218/year.

Initial (patent) design showed foamed cement which extended beyond the flanges of the metal studs to reduce thermal shorts – inspectors objected to the attachment of board which was through a portion of the foamed cement; consequently, design was changed to not include the foam extension.

Option Name: PVC Clip
Option Number: 21

Option Design Category:

Frame Insulating Fitting	X
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural Insulating Panels	
Other:	

Description: Extruded PVC clip that attaches along the length of the flange of the C to form a thermal break with about a 5 mm air gap.

Estimated Additional R-Value: R-3.4

Estimated Marginal Material Cost (\$/ft²):

Estimated Marginal Labor Cost (\$/ft²): Low

Additional Advantages/Liabilities:

Comments: The New Zealand study (below) indicated that in testing of five types of thermal breaks, using “Triple-S” strips (over flange) and sheathing, EPS strips and sheathing, and the PVC clip, that the insulation values for all were comparable.

References:

1. “The Thermal Insulation Performance of Lightweight Steel Framed External Wall Elements”, HERA Report #R4-72, January 1993.

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Insulated Drywall

Option Number: 22

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Insulation is laminated to drywall, adding a thermal bridge without the necessity of an additional installation step.

Estimated Additional R-Value: R-7.2 for 1” of urethane foam

Estimated Marginal Material Cost (\$/ft²): Low

Estimated Marginal Labor Cost (\$/ft²): None- Low

Additional Advantages/Liabilities: Probably very effective in eliminating ghosting. Potential for sound attenuation. May be detail problems. Simple solution – avoids inspection problems.

State of Commercialization: Available from Agile Building Systems, Williamsport, PA, 888-326-5640

References:

1. Agile Building Systems, manufacturer’s literature.

Additional Notes:

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Spray-In Insulation
Option Number: 23

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	
Other: Spray-in insulation	X

Description: Insulation is spray-applied to the interior stud and sheathing, partially or fully filling the wall space. Most common types of spray-in materials are standard urethane and lower density modified urethane (Icynene), cellulose and rock wool fiber spray-in.

Estimated Additional R-Value: Nominal (not additional) R-values are about R-6 for polyurethane, R-3.6 for Icynene, R-3.5 to 3.8 for cellulose and R-3.8 for rockwool.

Estimated Marginal Material Cost (\$/ft²): Medium - High

Estimated Marginal Labor Cost (\$/ft²): Medium

Additional Advantages/Liabilities: Foams serve as vapor barrier. If sprayed to the outside edge of a furring strip or similar, foam or cellulose could provide very effective ghosting reduction, plus potential for sound attenuation. (However, spray foams are sometimes not sprayed to full depth of wall because of price).

State of Commercialization: Commercially available and widely used.

References:

3. Icynene internet site, <http://icynene.on.ca>
4. "Energy Source Directory," Iris Communications, Inc., 1994.

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: ExcelBoard Structural Insulation
Option Number: 24

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: A 5/8” thick exterior sheathing with both structural and insulation properties composed of foam and aspen wood fibers with a water-resistant kraft paper backing. Product is intended for use as part of an exterior finish and insulation system (EIFS).

Estimated Additional R-Value: Board value is about R-2.4². If plywood is eliminated, additional resistance is approximately R-1.8.

Estimated Marginal Material Cost (\$/ft²): Board cost is between \$0.50 and \$0.75 per ft², depending on quantity². Additional bracing may be required. Cost of plywood sheathing is eliminated.

Estimated Marginal Labor Cost (\$/ft²): Low - None

Additional Advantages/Liabilities: May be applied directly to studs spaced 16” on center or less. Manufacturer currently recommends use of bracing for racking resistance. Although the system has been tested structurally for use without bracing, retesting is required for a system that includes a vapor barrier underneath the board, which is the recommended system. Requires use of proprietary industrial adhesive (with implications for meeting code requirements in seismic areas). Requires foaming of joints to seal, and application of board over house wrap. Allows direct application of mesh and synthetic stucco finish, with potential for lower overall cost.

State of Commercialization: Commercially available through Universal Polymers, Inc. (UPI), 319 North Main, Springfield, Missouri, 417-862-4547, 800-752-5403.

References:

1. “New Building Products,” 3:3 (April-May, 1997), NAHB Research Center
2. Conversation with Rick Franco, UPI, October 5, 1998.

Additional Notes: Material is approximately 5 lbs/ft³ density

Option Name: Diversitec Structural Insulation
Option Number: 25

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Rigid foam sheets with fiber and cement/resin faces to provide structural properties

Estimated Additional R-Value: Approximately R-4.5 for 1” of foam, assuming elimination of ½” plywood sheathing.

Estimated Marginal Material Cost (\$/ft²): Approximately \$0.30/ft² board cost, less cost of eliminated plywood, plus additional cost for fasteners or adhesives.

Estimated Marginal Labor Cost (\$/ft²): Low

Additional Advantages/Liabilities:

State of Commercialization: Not commercially available. Prototype boards being fabricated by Diversitec, Atlanta, GA.

References:

1. James (Ed) Hudson, NAHB Research Center

Additional Notes:

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

Option Name: Reoriented Fiberglass Batts

Option Number: 26

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	X
Structural/Insulating Panels	
Other:	

Description: Fiberglass batts are reoriented, laid horizontally across both studs and wall spaces, creating a compressed insulation barrier between the stud and drywall. Installation is similar to commercial roof installation details.

Estimated Additional R-Value: R-1.0

Estimated Marginal Material Cost (\$/ft²): None - Low (Cost of fasteners and slightly greater amount of insulation)

Estimated Marginal Labor Cost (\$/ft²): Low

State of Commercialization: Technique used in commercial building construction

References:

1. "ASRAE 90.1 Compliance for Metal Buildings," North American Insulation Manufacturer's Association (NAIMA), Publication #MB304, October, 1997.
2. 1997 ASHRAE Fundamentals Handbook, page 22.4.

Assessment of design options is made with respect to a "baseline" 4'X8' wall system of approximately R-7.9 overall, consisting of:

- ½" plywood sheathing
- 3 ½" 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½" gypsum board

Option Name: Insulated Siding

Option Number: 27

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	
Other: Insulated Siding Material	X

Description: Vinyl or other siding product is provided with foam insulation either laminated to the back of the siding or provided separately.

Estimated Additional R-Value: TechWall siding R-value of 4.3. Climatic siding R-3.8.

Estimated Marginal Material Cost (\$/ft²): Medium - High

Estimated Marginal Labor Cost (\$/ft²): Low

Additional Advantages/Liabilities: May increase tendency toward moisture collection between siding and sheathing.

State of Commercialization: Available from several manufacturers:

1. TechWall siding by Crane Plastics Co., Columbus, OH, 614-443-4891. One distributor is United Wholesale, Baltimore, MD
2. Climatic Insulated Siding by Gentek Building Products, Ltd.
3. Amazing Insulation by Amazing Siding, www.amazingsiding.com.

References:

1. Conversation with Crane Plastics Co. representative, September 1998.
2. Gentek and AmazingWall manufacturer literature.

Option Name: Interior Rigid Insulation
Option Number: 28

Option Design Category:

Frame Insulating Fitting	
Insulating Coating	
Stud Modification	
Wall System Modification	
Structural/Insulating Panels	X
Other:	

Description: Rigid foam sheets (e.g., polystyrene) used between studs and drywall.

Estimated Additional R-Value: R-3.85 for 1” expanded polystyrene foam with a density of 1.0 lbs/ft³ @ 75°F.

Estimated Marginal Material Cost (\$/ft²): Low-Medium

Estimated Marginal Labor Cost (\$/ft²): Low

Additional Advantages/Liabilities: Various mounting details may make the installation cost effective and improve buildability at the same time.

State of Commercialization: Commonly available material.

Assessment of design options is made with respect to a “baseline” 4’X8’ wall system of approximately R-7.9 overall, consisting of:

- ½” plywood sheathing
- 3 ½” 18 gauge steel framing, 24 inches on center
- R-13 fiberglass batt insulation
- ½” gypsum board

APPENDIX B
Thermal Options Cost Evaluation

Methodology

This cost analysis examines and calculates approximate costs to construct steel-framed wall panels measuring 8' by 8' square. This size corresponds to the panels thermally tested in the guarded hotbox apparatus. Utilizing panels will not reflect actual costs or r-values one expects from a completed wall construction in a residential structure, however, the relative values are similar, and valid cost comparisons can be made between different options. Relative cost comparisons mandates a baseline wall for all options to be compared to. Several different baseline walls were developed based on different comparisons that are taken. For example, the goal of this project is to have a steel-framed wall equivalent (or better) in cost and performance to wood-framed construction.

Most steel framing is spaced at 24 inches on-center, so the wood baseline would also be 24 inches on-center. However, 24-inch spacing is the exception for current practice, representing a small percentage of wood-framed homes. A second wood baseline was used incorporating stud spacing 16 inches on-center.

Additional baselines were developed using steel framing. Even if steel framed walls cannot be as cost effective as wood framed walls, a fundamental goal of this work would be to develop the most cost effective steel framed wall achievable. A total of 3 different steel baseline cases were developed which represent current construction practice in building shear walls. In California, nearly all-current construction utilizes X-bracing, thus this would be a current baseline. Building codes are starting to incorporate wood sheathing results for steel framing, so this method will become increasingly common. Two cases were developed using wood sheathing, one used screws while the other used pins to secure the wood.

The following list summarizes the different baseline wall sections:

- Wood Baseline 1 - framing 16" oc, 1/2" OSB, 1/2" drywall, fiberglass cavity insulation;
- Wood Baseline 2 - framing 24" oc, 1/2" OSB, 1/2" drywall, fiberglass cavity insulation;
- Steel Baseline 1 - framing 24" oc, 1/2" OSB screwed, 1/2" drywall, fiberglass cavity insulation;
- Steel Baseline 2 - framing 24" oc, 1/2" OSB pinned, 1/2" drywall, fiberglass cavity insulation;
- and
- Steel Baseline 3 - framing 24" oc, 6" X-bracing, 1/2" drywall, fiberglass cavity insulation.

Material and labor costs were calculated separately and combined for the total panel cost. Labor estimates are from 1998 and 1999 R. S. Means *Residential Cost Data*. In several instances, there are not published results available and an estimate was made based on NAHB Research Center staff expertise on requirements of residential construction and cold-formed steel construction. Labor costs are obtained by applying times estimates to an effective loaded labor rate of a two-man crew consisting of a carpenter and a helper¹.

Material costs represent list or published prices and do not reflect additional contractor discounts. Sources of the data included home supply centers (Lowe's, Home Depot), mail order industrial

¹ The labor rate is from Means 1998 *Residential Cost Data*. The rate of \$27.70 per hour is the average of Crew F-2 (\$31.70 & \$23.70 respectively).

supplier (McMaster-Carr), and calls to manufacturers or their designated representatives. In some cases items which are not widely available (i.e., pins) the manufacturer provided estimates based on historical cost data in their experience.

Assumptions

Table I - Fastener Quantities

Product	Comments	Spacing	16" oc	24" oc
4x8 insulation	installed vertically	12/24	60	54
2x8 insulation	installed horizontally	12/24	100	92
4x8 OSB	installed vertically	6/12	120	108
4x8 drywall	installed horizontally	6/12	104	88
wood framing	4 fasteners per stud	n/a	28	20
steel framing	4 fasteners per stud	n/a	28	20
x-bracing	4 fasteners per end	n/a	16	16
interior insulation	2 horizontal wood strips ¹	n/a	--	35
interior insulation	3 horizontal wood strips ²	n/a	--	45

Table II - Material Costs

Product	Units	Cost	Basis
wood 2x4	LF	\$0.255	per NAHB RC P.O. #21653 (Lowes): 12/11/98
wood 2x6	LF	\$0.43	per NAHB RC P.O. #21060 (Lowes): 6/22/98
steel 2x4 stud	LF	\$0.575	per Kevin Parker (Dietrich LA) - \$0.55-\$0.60/sf
steel 2x4 track	LF	\$0.50	per Kevin Parker (Dietrich LA) - \$0.50/sf
steel 2x6 stud	LF	\$0.775	per Kevin Parker (Dietrich LA) - \$0.75-\$0.80/sf
steel 2x6 track	LF	\$0.60	per Kevin Parker (Dietrich LA) - \$0.60/sf
6" x-bracing	LF	\$0.50	estimated same as 2x4 track
4x8 OSB	sheet	\$7.45	per NAHB RC P.O. #21653 (Lowes): 12/11/98
4x8 drywall	sheet	\$4.37	per NAHB RC P.O. #21653 (Lowes): 12/11/98
1/2" EPS	2x8 sheet	\$1.61	estimated: Price(1") - 0.5xPrice(2") + 0.5xPrice(1")
1" EPS	2x8 sheet	\$2.97	Home Depot <i>ProBook</i> , 1999 edition
2" EPS	2x8 sheet	\$5.71	Home Depot <i>ProBook</i> , 1999 edition
1/2" XPS	4x8 sheet	\$7.50	per Donny Dotson (OCF rep) - \$7.50/sheet
1" XPS	4x8 sheet	\$8.96	per Donny Dotson (OCF rep) - \$0.26-\$0.30/sf
2" XPS	4x8 sheet	\$17.92	per Donny Dotson (OCF rep) - \$0.52-\$0.60/sf
1/2" polyisocyanurate (7/16")	4x8 sheet	\$6.99	Home Depot <i>ProBook</i> , 1999 edition
1" polyisocyanurate	4x8 sheet	\$12.67	Home Depot <i>ProBook</i> , 1999 edition
2" polyisocyanurate	4x8 sheet	\$21.50	Home Depot <i>ProBook</i> , 1999 edition
thermal tape	LF	\$0.15	telephone conversation with Linda Lind, Shadwell Company
1/4" Fanfold	LF	\$0.021	Home Depot <i>ProBook</i> , 1999 edition

¹ For attaching floor and crown moulding.

² For attaching floor and crown moulding along with chair rail.

Table II - Material Costs (cont.)

Product	Units	Cost	Basis
3/8" Fanfold	LF	\$0.023	Home Depot <i>ProBook</i> , 1999 edition
R13 cavity	sf	\$0.21	Home Depot <i>ProBook</i> , 1999 edition
R19 cavity	sf	\$0.25	Home Depot <i>ProBook</i> , 1999 edition
3/4" EPS	2x8 sheet	\$2.29	average of 1/2" and 1" EPS
3/4" XPS	2x8 sheet	\$4.12	average of 1/2" and 1" XPS
1x3 furring	LF	\$0.1825	per telephone call to Lowe's (1/21/99)
steel z channel	LF	\$0.075	calculated based on Lowe's cost of partition studs adjusted for weight difference
12d nails	each	\$0.0200	
3" roofing nails	each	\$0.0064	per Washington Roofing, price based on 50 pounds
pins	each	\$0.0475	per Dave Nolan (ETF), price based on 1,000 units
3/4" #8 pan screws	each	\$0.1586	per McMaster-Carr (#102), price based on 100 units
Wind-lock S-1 screws	each	\$0.1130	per Wind-lock, price based on 1,000 units
Wind-lock S-3 screws	each	\$0.1600	per Wind-lock, price based on 1,000 units
#6 - 1-1/4" sharp point screws	each	\$0.0012	per McMaster-Carr (#102), price based on 1,000 units
#6 - 1-1/4" self-drilling screws	each	\$0.0078	per McMaster-Carr (#102), price based on 500 units
1-1/2" roofing nails	each	\$0.0028	1999 Home Depot <i>ProBook</i> , price based on 50 pounds
1-1/4" roofing nails	each	\$0.0024	1999 Home Depot <i>ProBook</i> , price based on 50 pounds

Table III - Labor Costs

Product	Units	Hours	Basis
wood 2x4 - 16" oc	LF	0.133	per Means 1998 <i>Residential Cost Data</i> (061 138 0207)
wood 2x4 - 24" oc	LF	0.107	per Means 1998 <i>Residential Cost Data</i> (061 138 0307)
steel 2x4 - 24" oc	LF	0.152	per Means 1999 <i>Residential Cost Data</i> (054 138 4150)
wood 2x6 - 16" oc	LF	0.148	per Means 1998 <i>Residential Cost Data</i> (061 138 0807)
wood 2x6 - 24" oc	LF	0.116	per Means 1998 <i>Residential Cost Data</i> (061 138 0907)
steel 2x6 - 24" oc	LF	0.158	per Means 1999 <i>Residential Cost Data</i> (054 138 4210)
x-bracing - 6" wide	each	1.0	per Means 1999 <i>Residential Cost Data</i> (054 104 0170)
1/2" OSB – nails or pins	fastener	0.011	per Means 1998 <i>Residential Cost Data</i> (061 154 0608)
1/2" OSB – screws	fastener	0.015	per Means 1998 <i>Residential Cost Data</i> x 1.39 ¹
1/2" drywall – wood	fastener	0.008	per Means 1998 <i>Residential Cost Data</i> (092 608 0300)
1/2" drywall – steel	fastener	0.011	per Means 1998 <i>Residential Cost Data</i> x 1.39
foam <= 1" (nailed)	fastener	0.010	per Means 1998 <i>Residential Cost Data</i> (072 100 1610-1640)
foam <= 1" (screwed)	fastener	0.014	per Means 1998 <i>Residential Cost Data</i> x 1.39

¹ The wood to steel fastening premium was calculated by averaging the ratio of Means steel to wood data for 2x4 and 2x6 walls, i.e.,

$$2x4: 0.152 / 0.107 = 1.42,$$

$$2x6: 0.158 / 0.116 = 1.35, \text{ therefore, average is } 1.39.$$

Table III - Labor Costs (cont.)

Product	Units	Hours	Basis
foam > 1" (nailed)	fastener	0.011	per Means 1998 <i>Residential Cost Data</i> (072 100 1650-1680)
foam > 1" (screwed)	fastener	0.015	per Means 1998 <i>Residential Cost Data</i> x 1.39
self-adhesive foam tape	LF	0.010	per Means 1998 <i>Residential Cost Data</i> , 1/3 of (079 204 0500)
"Snap-Cap" foam	all	0.33	estimate
"Fanfold"	all	1.0	estimate
R13 cavity insulation	sf	0.005	per Means 1998 <i>Residential Cost Data</i> (072 118 0080)
R19 cavity insulation	sf	0.006	per Means 1998 <i>Residential Cost Data</i> , (072 118 0141)
interior insulation w/ 1x3 furring, z-channel (screwed)	fastener	0.015	steel drywall estimate (see above)
interior insulation w/ 1x3 furring, z-channel (pinned)	fastener	0.012	screw estimate x 0.8

Results

In all comparisons of different insulation options, the relative ranking remained the same when compared to all five-baseline wall sections.

Table IV - Insulation Option Ranking

Insulation Option	Rank		
	Wood Sheathing with Screws	Wood Sheathing with Pins	X-bracing
1/2" EPS	4	4	9
1" EPS	8	8	13
2" EPS	12	14	21
1/2" XPS	10	10	12
1" XPS	11	11	15
2" XPS	17	18	22
1/2" polyisocyanurate	9	9	10
1" polyisocyanurate	13	15	20
2" polyisocyanurate	19	19	23
foam tape (int)	5	5	4
1/2" Snap-Cap (int)	1	1	1
1" Snap-Cap (int)	2	2	2
2" Snap-Cap (int)	3	3	3
1/4" Fanfold (int)	6	6	5
3/4" Fanfold (int)	7	7	6
EPS interior insulation, 2-1x3's (screwed)	14	n/a	18
EPS interior insulation, 2-1x3's (pinned)	n/a	12	7
EPS interior insulation, 3-1x3's (screwed)	15	n/a	16
EPS interior insulation, 3-1x3's (pinned)	n/a	13	8
XPS interior insulation, 2-1x3's (screwed)	16	n/a	17
XPS interior insulation, 2-1x3's (pinned)	n/a	16	11
XPS interior insulation, 3-1x3's (screwed)	18	n/a	19
XPS interior insulation, 3-1x3's (pinned)	n/a	17	14

Cost Calculation

Absolute Costs of Baseline Walls

Wall Description	2x4 Wall Construction			2x6 Wall Construction		
	Mat.	Labor	Total	Mat.	Labor	Total
Wood Baseline 1	\$55.01	\$71.19	\$126.20	\$69.90	\$76.12	\$146.02
Wood Baseline 2	\$51.16	\$65.70	\$116.86	\$63.36	\$69.36	\$132.72
Steel Baseline 1	\$72.77	\$89.37	\$162.14	\$84.93	\$92.47	\$177.40
Steel Baseline 2	\$77.06	\$81.76	\$158.83	\$89.22	\$84.86	\$174.09
Steel Baseline 3	\$70.87	\$89.96	\$160.83	\$83.03	\$93.06	\$176.10

Absolute Costs of Baseline Walls (Wood Sheathing with Screws)

Insulation Option ¹	2x4			2x6		
	Mat.	Labor	Total	Mat.	Labor	Total
1/2" EPS	\$79.43	\$107.09	\$186.52	\$91.59	\$110.20	\$201.79
1" EPS	\$84.91	\$107.09	\$192.01	\$97.07	\$110.20	\$207.27
2" EPS	\$95.83	\$108.87	\$204.70	\$107.99	\$111.97	\$219.96
1/2" XPS	\$87.90	\$107.09	\$195.00	\$100.06	\$110.20	\$210.26
1" XPS	\$90.84	\$107.09	\$197.94	\$103.00	\$110.20	\$213.20
2" XPS	\$108.74	\$108.87	\$217.61	\$120.90	\$111.97	\$232.87
1/2" polyisocyanurate	\$86.88	\$107.09	\$193.98	\$99.04	\$110.20	\$209.24
1" polyisocyanurate	\$98.26	\$107.09	\$205.36	\$110.42	\$110.20	\$220.62
2" polyisocyanurate	\$115.90	\$108.87	\$224.77	\$128.06	\$111.97	\$240.03
foam tape (int)	\$81.17	\$105.40	\$186.57	\$93.33	\$108.50	\$201.83
1/2" Snap-Cap (int)	\$80.61	\$98.51	\$179.12	\$92.77	\$101.61	\$194.38
1" Snap-Cap (int)	\$83.97	\$98.51	\$182.48	\$96.13	\$101.61	\$197.74
2" Snap-Cap (int)	\$86.77	\$98.51	\$185.28	\$98.93	\$101.61	\$200.54
1/4" Fanfold (int)	\$73.93	\$117.07	\$191.00	\$86.09	\$120.17	\$206.26
3/4" Fanfold (int)	\$74.08	\$117.07	\$191.15	\$86.24	\$120.17	\$206.41
EPS interior insulation, 2-1x3's (screwed)	\$91.23	\$116.47	\$207.70	\$103.39	\$119.58	\$222.97
EPS interior insulation, 3-1x3's (screwed)	\$94.42	\$116.47	\$210.89	\$106.58	\$119.58	\$226.16
XPS interior insulation, 2-1x3's (screwed)	\$98.53	\$116.47	\$215.00	\$110.69	\$119.58	\$230.27
XPS interior insulation, 3-1x3's (screwed)	\$101.72	\$116.47	\$218.19	\$113.88	\$119.58	\$233.46

¹ All walls are steel framing 24" oc, 1/2" OSB screwed, 1/2" drywall, fiberglass cavity insulation.

Absolute Costs of Baseline Walls (Wood Sheathing with Pins)

Insulation Option ¹	2x4			2x6		
	Mat.	Labor	Total	Mat.	Labor	Total
1/2" EPS	\$83.72	\$99.49	\$183.21	\$95.88	\$102.59	\$198.47
1" EPS	\$89.20	\$99.49	\$188.69	\$101.36	\$102.59	\$203.95
2" EPS	\$100.12	\$101.26	\$201.38	\$112.28	\$104.36	\$216.65
1/2" XPS	\$92.19	\$99.49	\$191.68	\$104.35	\$102.59	\$206.94
1" XPS	\$95.14	\$99.49	\$194.63	\$107.30	\$102.59	\$209.89
2" XPS	\$113.03	\$101.26	\$214.29	\$125.19	\$104.36	\$229.56
1/2" polyisocyanurate	\$91.17	\$99.49	\$190.66	\$103.33	\$102.59	\$205.92
1" polyisocyanurate	\$102.56	\$99.49	\$202.05	\$114.72	\$102.59	\$217.31
2" polyisocyanurate	\$120.19	\$101.26	\$221.45	\$132.35	\$104.36	\$236.72
foam tape (int)	\$85.46	\$97.79	\$183.26	\$97.62	\$100.89	\$198.52
1/2" Snap-Cap (int)	\$84.90	\$90.90	\$175.81	\$97.06	\$94.00	\$191.07
1" Snap-Cap (int)	\$88.26	\$90.90	\$179.17	\$100.42	\$94.00	\$194.43
2" Snap-Cap (int)	\$91.06	\$90.90	\$181.97	\$103.22	\$94.00	\$197.23
1/4" Fanfold (int)	\$78.22	\$109.46	\$187.69	\$90.38	\$112.56	\$202.95
3/4" Fanfold (int)	\$78.37	\$109.46	\$187.83	\$90.53	\$112.56	\$203.09
EPS interior insulation, 2-1x3's (pinned)	\$93.23	\$103.45	\$196.68	\$105.39	\$106.55	\$211.94
EPS interior insulation, 3-1x3's (pinned)	\$95.77	\$103.45	\$199.21	\$107.93	\$106.55	\$214.47
XPS interior insulation, 2-1x3's (pinned)	\$100.53	\$103.45	\$203.98	\$112.69	\$106.55	\$219.24
XPS interior insulation, 3-1x3's (pinned)	\$103.07	\$103.45	\$206.51	\$115.23	\$106.55	\$221.77

Absolute Costs of Baseline Walls (X-bracing)

Insulation Option ²	2x4			2x6		
	Mat.	Labor	Total	Mat.	Labor	Total
1/2" EPS	\$87.71	\$114.60	\$202.31	\$99.87	\$117.71	\$217.57
1" EPS	\$93.15	\$114.60	\$207.75	\$105.31	\$117.71	\$223.01
2" EPS	\$108.43	\$117.07	\$225.50	\$120.59	\$120.17	\$240.76
1/2" XPS	\$91.97	\$114.60	\$206.58	\$104.13	\$117.71	\$221.84
1" XPS	\$94.89	\$114.60	\$209.50	\$107.05	\$117.71	\$224.76
2" XPS	\$116.31	\$117.07	\$233.38	\$128.47	\$120.17	\$248.64
1/2" polyisocyanurate	\$90.95	\$114.60	\$205.56	\$103.11	\$117.71	\$220.82
1" polyisocyanurate	\$102.31	\$114.60	\$216.92	\$114.47	\$117.71	\$232.18
2" polyisocyanurate	\$122.51	\$117.07	\$239.58	\$134.67	\$120.17	\$254.84
foam tape (int)	\$79.27	\$105.99	\$185.26	\$91.43	\$109.09	\$200.52
1/2" Snap-Cap (int)	\$78.71	\$99.10	\$177.81	\$90.87	\$102.20	\$193.08
1" Snap-Cap (int)	\$82.07	\$99.10	\$181.17	\$94.23	\$102.20	\$196.44
2" Snap-Cap (int)	\$84.87	\$99.10	\$183.97	\$97.03	\$102.20	\$199.24
1/4" Fanfold (int)	\$72.03	\$117.66	\$189.69	\$84.19	\$120.76	\$204.96
3/4" Fanfold (int)	\$72.18	\$117.66	\$189.84	\$84.34	\$120.76	\$205.10

¹ All walls are steel framing 24" oc, 1/2" OSB pinned, 1/2" drywall, fiberglass cavity insulation.

² All walls are steel framing 24" oc, 6" x-bracing, 1/2" drywall, fiberglass cavity insulation.

Absolute Costs of Baseline Walls (X-bracing)

Insulation Option ¹	2x4			2x6		
	Mat.	Labor	Total	Mat.	Labor	Total
EPS interior insulation, 2-1x3's (screwed)	\$99.82	\$117.07	\$216.89	\$111.98	\$120.17	\$232.15
EPS interior insulation, 2-1x3's (pinned)	\$87.04	\$111.65	\$198.68	\$99.20	\$114.75	\$213.95
EPS interior insulation, 3-1x3's (screwed)	\$92.52	\$117.07	\$209.59	\$104.68	\$120.17	\$224.85
EPS interior insulation, 3-1x3's (pinned)	\$89.57	\$111.65	\$201.22	\$101.73	\$114.75	\$216.48
XPS interior insulation, 2-1x3's (screwed)	\$96.63	\$117.07	\$213.70	\$108.79	\$120.17	\$228.96
XPS interior insulation, 2-1x3's (pinned)	\$94.34	\$111.65	\$205.98	\$106.50	\$114.75	\$221.25
XPS interior insulation, 3-1x3's (screwed)	\$99.82	\$117.07	\$216.89	\$111.98	\$120.17	\$232.15
XPS interior insulation, 3-1x3's (pinned)	\$96.87	\$111.65	\$208.52	\$109.03	\$114.75	\$223.78

¹ All walls are steel framing 24" oc, 6" x-bracing, 1/2" drywall, fiberglass cavity insulation.



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