Real R-Value of Exterior Insulated Wall Assemblies

Mark Lawton, P.Eng.
Patrick Roppel, P.Eng.
David Fookes, P.Eng.
Anik Teasdale St Hilaire, PhD.
Daniel Schoonhoven

ABSTRACT

The recent drive towards sustainable building construction has placed new emphasis on the provision of durable wall assemblies that provide a high effective resistance to heat flow (R-Value). The authors' practice focuses on large multi-residential, commercial and institutional buildings constructed of concrete, steel, masonry and glazing systems. In these types of buildings, and particularly in the temperate climate of British Columbia's Lower Mainland, thermal performance has not historically been treated as a high priority item. Now, however, the requirements of sustainability programs such as LEED are requiring architects to design wall systems that provide high levels of thermal resistance. Architects are often shocked at the difference between effective R-value of a proposed opaque wall assembly and the nominal R-value of installed insulation materials. The difference is a result of the thermal bridges associated with structural elements and connections that pass through the building thermal envelope.

The authors have undertaken analyses, using the modeling program THERM, to numerically evaluate the effective thermal resistance of some typical wall assemblies used in high-rise residential buildings. We evaluated the impact of slab edge detailing and a variety of secondary structural elements needed to support the cladding. We have developed a method of presenting the information in a manner that architects can practically use to determine actual insulation thicknesses required to obtain the overall walls' desired thermal performance.

INTRODUCTION

A number of factors are causing architects to place more attention on the overall, effective thermal resistance of opaque wall assemblies used in non-combustible buildings.

Clients are demanding that more attention be paid to sustainability and energy conservation either directly by specification, or by participation in programs such as LEED. Energy conservation requirements are typically defined by reference to standards such as ASHRAE 90.1 or Canada's National Energy Code for Buildings. These standards have both prescriptive and performance based compliance paths.

Mark Lawton is Technical Director for Building Engineering, **Patrick Roppel** and **David Fookes** are project engineers, **Anik Teasdale St Hilaire** is a building science consultant and **Daniel Schoonhoven** is a co-op student. All are with Morrison Hershfield Ltd., Vancouver, BC, Canada

Both require knowledge of the effective thermal resistance of opaque enclosure assemblies.

A major challenge in non-combustible buildings is that wall assemblies often have highly conductive structural elements passing through the thermal insulation so that the overall or effective thermal resistance of opaque wall assemblies can be much less than the nominal R-value of the installed thermal insulation. With the complex, three-dimensional heat flow paths in these "commercial" wall assemblies, calculating the effective thermal resistance is a difficult process that requires tools such as 2-D or 3-D heat flow computer simulation programs. Application of such tools is beyond the capability of most architectural offices. The challenge is such that in most jurisdictions where compliance with ASHRAE 90.1 is required by code, bylaw or specification, the impact of thermal bridges created by cladding attachment has historically been ignored. This is now changing. The importance of thermal bridges related to cladding attachment in common wall assembles is becoming increasingly recognized (Peer 2007), and there are even initiatives to better define actual thermal performance of wall assemblies by test.

The authors were directly confronted with the issues on a major residential project in Vancouver, Canada where they acted as the Building Envelope Professionals undertaking design and construction review of the enclosure systems. The project encompassed a total of 15 buildings; typically 5-13 storeys designed by six different architects. The development has high sustainability requirements including compliance with LEED Gold. Complicating matters was the fact that the project has to be complete by an immovable date so that iterative design cycling had to be minimized.

The mechanical engineer for the project carried out initial energy use modeling and defined thermal performance requirements for the enclosure assemblies. The provided requirements were:

Table 1: Thermal Resistances assumed by Modeling

	U value $W/m^2/^oC$ ($BTU/ft^2/^oF$)	R value	Shading coefficient
Roof	.238 (.0440)	24	
Walls	.379 (.067)	15	
Windows	2.335 (.411)	2.4	0.69
Floors	0.47 (.0827)	12	

Each of the architects turned to the authors firm to help them design wall systems that met these performance requirements in addition to all the other performance, constructability and budget restraints imposed in the design process. Many of the architects were surprised to learn that the wall systems that they had used in previous high-rise residential construction fell far short of the defined thermal resistance requirement, primarily because of the influence of thermal bridges. They obviously had questions about whether they could simply modify the types of assemblies that they had experience with by, for example, adding insulation or whether that had to make a dramatic departure from their initial design assumptions and if so, to what?

In an effort to assist architects, the authors undertook a program of modeling typical systems with THERM and created a method of transmitting results in a manner that aided the decision making process of the architects.

TYPICAL WALL SYSTEMS

Most regions develop "locally typical" methods of constructing high-rise residential buildings. What is locally typical depends on climate, the cost and availability of components and assemblies and what the local design and construction community is comfortable with and finds cost effective.

In Vancouver, typical high-rise residential buildings can be said to have the following characteristics.

- They are concrete-framed
- Exposed slab edges including projecting balconies and "eyebrows" are common
- They use a high percentage of glazing, particularly to the "view" directions of north (mountains) and west (ocean).
- Glazing is often "window-wall", a one storey high glazing system with vision and opaque sections and frames that rest on each slab but have a bypass that covers the slabs to give an appearance similar to curtainwall.
- Opaque walls include:
    - mass concrete walls with interior insulation and an elastomeric coating,
    - steel stud backup walls with rainscreen cladding of some sort (historically, insulation was confined to the stud cavity, more recently having some or all the insulation outboard of the exterior sheathing is common practice),
    - masonry veneer over steel stud or poured concrete back walls are increasingly used as architectural accents
- Roofs are typically protected membrane roofs on concrete slabs

For the specific project being discussed, the wall systems being proposed by the architects could generally be classified into two basic types, as follows:

- Masonry clad walls supported by shelf angles at each slab and masonry ties on 24″ x 16″ centers to steel stud backup walls. On steel stud walls, a membrane adhered to the exterior sheathing acts as the air barrier, vapour barrier and interior moisture barriers. The primary insulation is placed outside the membrane and there may or may not be additional insulation placed in the stud cavity.
- "Rainscreen" cladding systems made from metal panels, fritted glass, cement board, or terra cotta supported on z-girts back to the studs of the back up wall. Again a membrane adhered to the exterior sheathing acts as the air barrier, vapour barrier and interior moisture barriers. The primary insulation is placed

outside the membrane and there may or may not be additional insulation placed in the stud cavity. There can be significant variation in the pattern of framing that passes through the exterior insulation depending on the cladding system.

The above wall systems readily transfer to other regions of North America.

Analysis of the effect on thermal performance of the type of alternate cladding attachment and slab edge configuration was the primary function of our work.

Modeling Methods

Analysis was carried out using the thermal modeling computer program THERM, developed and maintained by Lawrence Berkley National Laboratory. Modeling was completed for a number of different steel stud wall systems and cladding support scenarios.

Specific cases that were modeled included:

Brick veneer:

- With brick bearing on slabs (Figure 1)
- With brick bearing on ¼″ thick shelf angles bolted to slabs (Figure 2).
- With brick bearing on ¼″ thick shelf angles mounted on 3″x ¼″ steel brackets spaced at 24″.

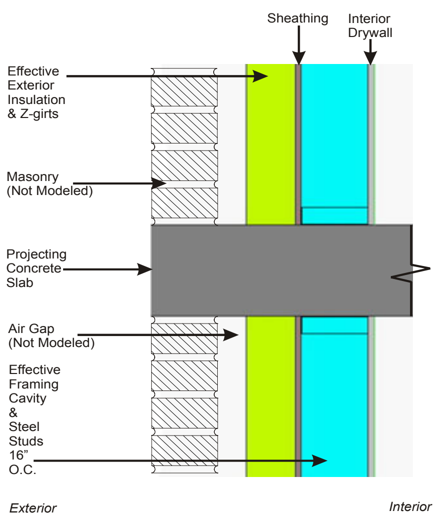


Figure 1: exposed slab edge

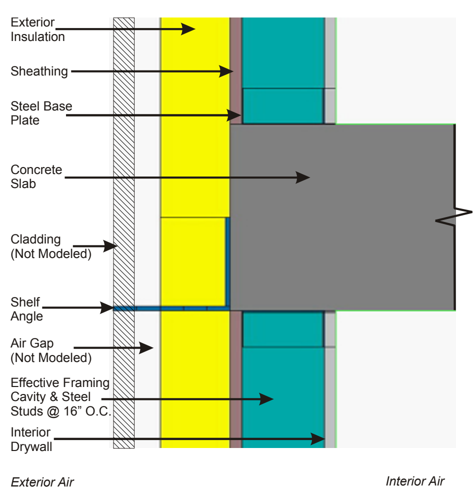


Figure 2: Shelf angle bolted to slab

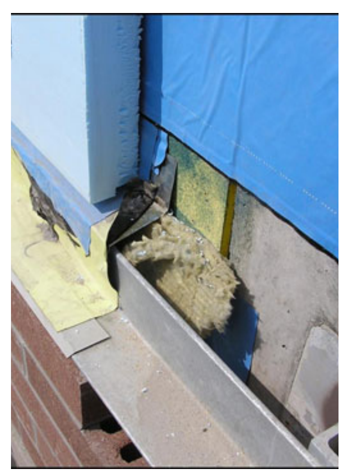


Figure 3: Shelf angle on brackets

Rainscreen cladding:

- With vertical z-girts on 16″ centers (Figure 4)
- With horizontal z-girts on 24″ centers
- With thermally broken vertical z-girts on 16″ centers (Figure 5)
- With vertical z-girts mounted on horizontal z-girts and two layers of insulation (Figure 6)

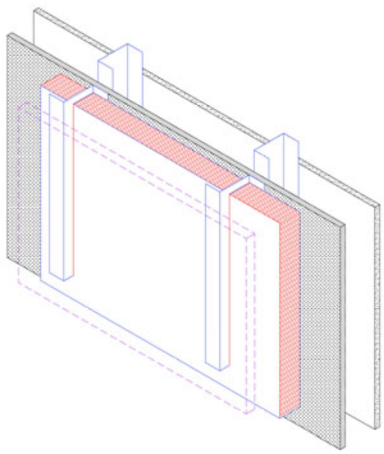


Figure 4: Vertical z-girts

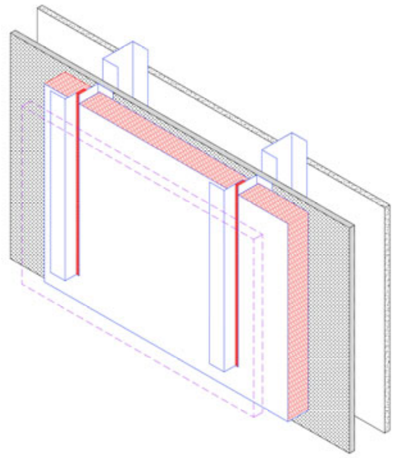


Figure 5: Thermally Broken Vertical z-girts

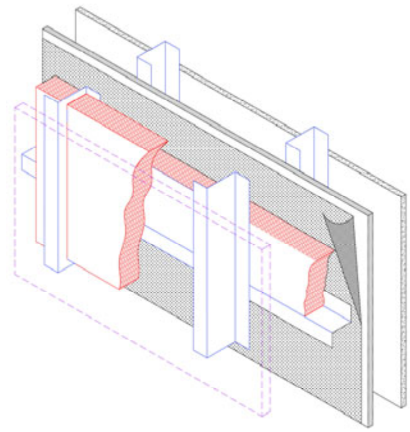


Figure 6: Vertical and horizontal z-girts

All cases were modeled with both 3 ½″ and 5 ½″ 18 gauge steel stud framing, and for both insulated and non-insulated frame cavities. Exterior insulation was modeled in a range of thicknesses and for several different insulation types. For each of the above cases, modeling was also carried out to determine the effective R-value of regions near concrete slabs. These R-values were lower than that of the surrounding wall due to the thermal bridging effect of the concrete slab. Modeled slab data was averaged into the appropriate R-value tables, with the assumption of 8ft ceilings. The effects of different slab edge details on overall wall R-value may be seen in Tables 3 and 4.

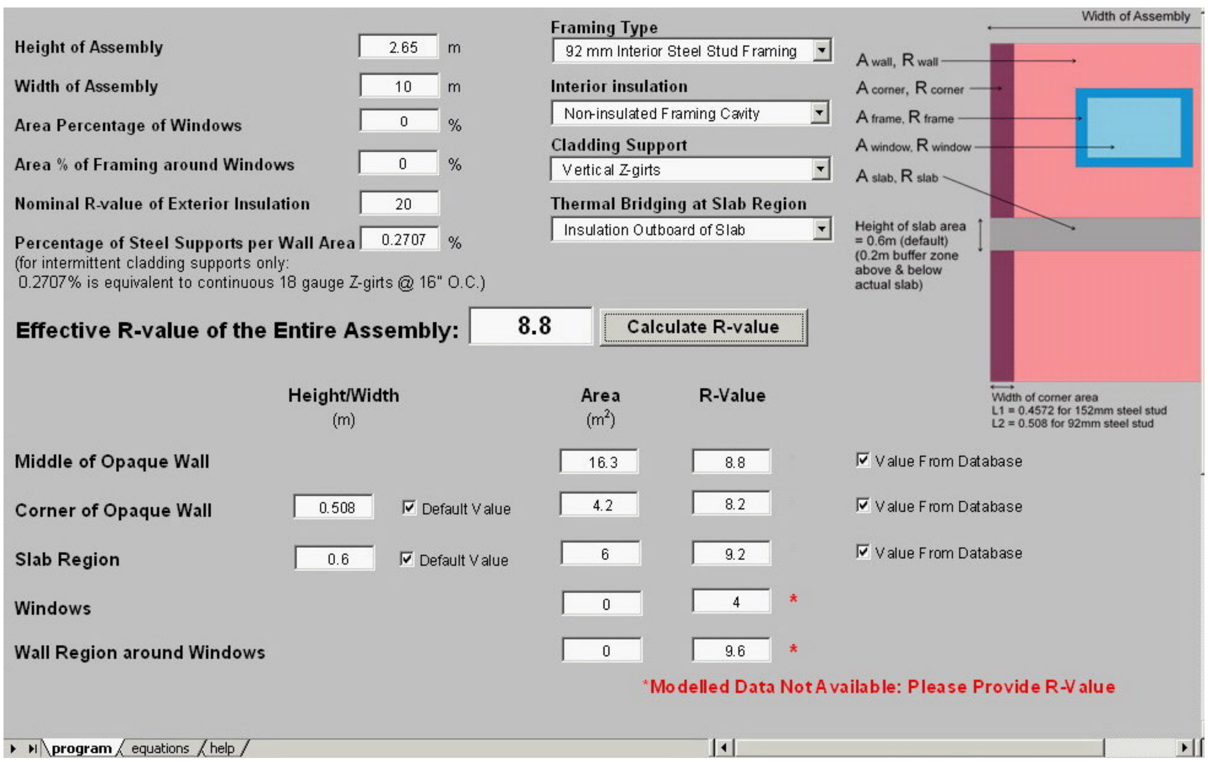
Important assumptions made in the modeling procedure include the following:

- Exclusion of exterior rainscreen cladding / masonry, due to the complex 3-D nature of convection and ventilation through the air gap between exterior insulation and cladding. Note that it is the different connection details of exterior claddings that significantly influence envelope thermal performance, and not so much the cladding itself, either masonry or rainscreen. The contribution of either masonry or rainscreen cladding to envelope thermal performance is not greatly significant.
- Use of a 2-D model, when actual heat flow is in three dimensions. This approximation was necessary due to the 2-D limitation of the software used (THERM). As a result of the use of a 2-D model, R-values reported for wall sections containing a combination of materials represent an approximation of the actual heat flow path and thermal resistance.
- Steady-state model (ignores thermal mass).
- Exclusion of membranes, vapour barriers, etc. from the model due to their negligible thermal resistances.

For those interested in the modeling process used, refer to Appendix A for detailed information on modeling procedures, boundary conditions used, calculations and observations.

Information Transfer Method

We have worked on a variety of ways of summarizing results of multiple simulation results. Appendix A contains some examples of analysis sheets developed for internal use. We have even created a simple program which allows the user to select architectural design features and outputs the overall effective R-value of the assembly. The program utilizes a database of modeled data (from THERM) and selects the appropriate data for the input information. The additional thermal bridging effects of slabs and corner assemblies are also accounted for by the program. The user can also input glazing information (thermal resistance and surface area) if it is desired to include window area in the calculation of effective R-value. A screenshot of the program is shown below.



Most of our architectural clients, however, are not particularly interested in the relative effectiveness of specific details. Their critical questions are much more fundamental. They think in systems, materials and dimensions. For them we have developed a tabular method of presenting results.

Modeled output is recorded in tables, presented as the effective R-value actually reached for a particular nominal R-value (or thickness of insulation). An architect can select the appropriate table, depending on wall construction and slab details, select the

R-value closest to that required by specification or otherwise, and look across the table to see the necessary insulation thickness for common insulation types and cladding systems. Alternatively, if the design type and thickness of exterior insulation is known, the effective R-value of the assembly for each cladding support style can be read off, as is shown by the arrows in the sample table below.

Table 2: Summary of Effective Thermal Resistances for Exterior Insulated Walls (No Insulation in Frame Cavity, Slab Effects Ignored)

Nominal Wall R-Value	Insulation Thickness (Inches)			Effective Wall R-Value for Various Cladding Attachments			
	Mineral Wool	EXPS	Spray foam	Vert. Girts	Hor. Girts	Broken Vertical Girts	Vert. & Hor. Girts
33.1	7.0	5.9	4.9	10.6			
28.9	6.0	5.0	4.2	9.8	13.5	14.6	16.8
24.7	5.0	4.2	3.5	9.0	12.3	13.4	15.0
20.5	4.0	3.4	2.8	8.2	11.0	12.1	13.2
16.3	3.0	2.5	2.1	7.3	9.5	10.5	11.3
12.1	2.0	1.7	1.4	6.1	7.7	8.6	8.8
7.9	1.0	0.8	0.7	4.8	5.6		
5.8	0.5	0.4	0.4	3.9	4.2		
3.7	0.0	0.0	0.0	2.6	2.6		

Table 3 and Table 4 summarize modeling results for masonry and stud supported cladding systems that consider insulation material and thickness, cladding support system and slab edge treatment. Table 3 presents results for cases where all insulation is installed outboard of the stud cavity and Table 4 assumes that there is an additional 5.5 inches of batt insulation (nominal R20) in a 5.5” stud cavity.

These tables clearly show the huge impact thermal bridges have on effective thermal resistance. The impacts may be obvious to those familiar with three dimensional heat transfers but are not so obvious to others.

Some notable observations include

- When there are major thermal bridges such as non-thermally broken z-girts, the effectiveness of insulation is remarkably low to start with, and decreases with the depth of insulation installed. This is explainable by noting that when high heat flow paths exist, reducing the heat flow of parallel paths will have limited benefit.
- Many building science specialists recommend having all insulation installed outboard of the stud cavity to help keep the structural elements warm and dry. To many practitioners it seems a waste not to add cheap insulation in the stud cavity. Comparing Table 4 with Table 3 shows how limited the thermal benefit of stud cavity insulation can be.

Table 3: Summary of Effective Thermal Resistances for Walls and Slab Regions (Exterior Insulation Only, No Insulation in Frame Cavity) (Based on a 2.65m Slab-to-Slab Height)

Type of Thermal Bridging at Slab	Nominal Wall R-Value	Insulation Thickness (Inches)			Effective Wall R-Value for Various Cladding Attachments (hr·ft^2·°F/Btu)			
		Mineral Wool	EXPS	Spray foam	Vert. Girts	Hor. Girts	Vert. & Hor. Girts	2″ x 1/16″ Brick Ties
Exposed Concrete Slab or Balcony	33.1	7.0	5.9	4.9	7.8	9.9	11.1	12.1
	28.9	6.0	5.0	4.2	7.4	9.4	10.3	11.2
	24.7	5.0	4.2	3.5	6.9	8.7	9.4	10.2
	20.5	4.0	3.4	2.8	6.3	7.9	8.5	9
	16.3	3.0	2.5	2.1	5.7	7	7.6	7.8
	12.1	2.0	1.7	1.4	5.1	6	6.4	6.4
	7.9	1.0	0.8	0.7	4.2	4.7		4.8
	5.8	0.5	0.4	0.4	3.4	3.8		3.8
	3.7	0.0	0.0	0.0	2.6	2.6		2.6
Exterior Insulation Placed Outboard of Slab	33.1	7.0	5.9	4.9	10.6	13.4		
	28.9	6.0	5.0	4.2	10	12.6		
	24.7	5.0	4.2	3.5	9.1	11.5		
	20.5	4.0	3.4	2.8	8.2	10.3		
	16.3	3.0	2.5	2.1	7.3	9		
	12.1	2.0	1.7	1.4	6.3	7.5		
	7.9	1.0	0.8	0.7	4.8	5.4		
	5.8	0.5	0.4	0.4	3.8	4.2		
	3.7	0.0	0.0	0.0	2.6	2.6		
¼” thick shelf angle bolted to slab	33.1	7.0	5.9	4.9				13.8
	28.9	6.0	5.0	4.2				12.8
	24.7	5.0	4.2	3.5				11.5
	20.5	4.0	3.4	2.8				10.1
	16.3	3.0	2.5	2.1				8.7
	12.1	2.0	1.7	1.4				7.1
	7.9	1.0	0.8	0.7				5.1
	5.8	0.5	0.4	0.4				4
	3.7	0.0	0.0	0.0				2.6
Shelf Angle fastened to 3”x ¼” steel brackets spaced at 24” o.c.	33.1	7.0	5.9	4.9				16.8
	28.9	6.0	5.0	4.2				15.2
	24.7	5.0	4.2	3.5				13.5
	20.5	4.0	3.4	2.8				11.6
	16.3	3.0	2.5	2.1				9.7
	12.1	2.0	1.7	1.4				7.7
	7.9	1.0	0.8	0.7				5.3
	5.8	0.5	0.4	0.4				4.1
	3.7	0.0	0.0	0.0				2.6

Table 4: Summary of Effective Thermal Resistances for Walls and Slab Regions (Exterior Insulation + 5.5″ Batt Insulation in 5.5″ Frame Cavity) (Based on a 2.65m Slab-to-Slab Height)

Type of Thermal Bridging at Slab	Nominal Wall R-Value	Insulation Thickness (Inches)			Effective Wall R-Value for Various Cladding Attachments ($hr \cdot ft^2 \cdot °F/Btu$)			
		Mineral Wool	EXPS	Spray foam	Vert. Girts	Hor. Girts	Vert. & Hor. Girts	2″ x 1/16″ Brick Ties on 16"x 24" grid
Exposed Concrete Slab or Balcony	50.0	7.0	5.9	4.9	10.1	13		13.8
	45.8	6.0	5.0	4.2	9.7	12.4		12.9
	41.6	5.0	4.2	3.5	9.2	11.6		11.8
	37.4	4.0	3.4	2.8	8.7	10.9		11
	33.2	3.0	2.5	2.1	8.1	9.9		9.9
	29.0	2.0	1.7	1.4	7.6	8.9		8.8
	24.8	1.0	0.8	0.7	7	7.8		
	22.7	0.5	0.4	0.4	6.6	7		
	20.6	0.0	0.0	0.0	6.1	6.2		
Exterior Insulation Placed Outboard of Slab	50.0	7.0	5.9	4.9	14.9	20.3		
	45.8	6.0	5.0	4.2	14.2	19.2		
	41.6	5.0	4.2	3.5	13.3	17.7		
	37.4	4.0	3.4	2.8	12.5	16.3		
	33.2	3.0	2.5	2.1	11.6	14.6		
	29.0	2.0	1.7	1.4	10.5	12.6		
	24.8	1.0	0.8	0.7	9	10.1		
	22.7	0.5	0.4	0.4	7.9	8.5		
	20.6	0.0	0.0	0.0	6.1	6.3		
¼" thick shelf angle bolted to slab	50.0	7.0	5.9	4.9				16
	45.8	6.0	5.0	4.2				14.8
	41.6	5.0	4.2	3.5				13.6
	37.4	4.0	3.4	2.8				12.4
	33.2	3.0	2.5	2.1				11.3
	29.0	2.0	1.7	1.4				10
	24.8	1.0	0.8	0.7				8.4
	22.7	0.5	0.4	0.4				7.3
	20.6	0.0	0.0	0.0				6

- It is interesting that masonry cladding alternatives can have superior thermal performance to common rainscreen panel claddings. This is due, not to their actual thermal properties, but to the nature of their attachment to the building with intermittently spaced brick ties, rather than by continuous sheet steel components.

- The thermal performance of rainscreen panel claddings is strongly dependant on the nature of the structural attachment. The use of attachments that provide significant reductions in thermal bridging such as thermally broken vertical z-girts or combined horizontal and vertical z-girts, provide large improvements in the effective thermal resistances of wall assemblies.

Clearly there needs to be more attention paid to using cladding support systems that reduce thermal bridging. Peer commented on several systems that could be fabricated or were available in Europe. One approach to minimizing thermal bridging is to use attachment methods that minimize the cross sectional area of metal that passes through the insulation. Another approach is to thermally break the structural components passing through the insulation.

SUMMARY AND CONCLUSIONS

The modeling completed in this study has established values for the effective thermal resistances of common wall systems, and quantified the benefits associated with reducing the amount of thermal bridging elements passing through a building thermal envelope. This modeling is hardly innovative. However the presentation of results in a tabular format have proven to be useful to our architectural clients on the referenced project and several subsequent ones

It is anticipated that the tables discussed above will prove a useful aid to architects in meeting design requirements for thermal performance.

REFERENCES

ASHRAE. 2005. 2005 ASHRAE Handbook – Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2005

ASHRAE. 2004. *ANSI/ASHRAE/IESNA. Standard 90.1-2004, Energy standard for buildings except low-rise residential buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ISSN 1041-2336

National Research Council of Canada 1995 *Canadian National Energy Code for Buildings*

Peer, L.B.B. 2007 *Practical Use of Thermal Breaks in Cladding Support Systems* Buildings X Conference, Clearwater Beach, Florida December 2007.

For further reading on thermal bridging in relation to wall thermal performance:

Study on heat transfer of light steel-framed composite walls in cold areas. Cui, Yong-Qi (School of Municipal and Environmental Engineering, Harbin Institute of Technology); Wang, Zhao-Jun; Zhang, Su-Mei. Source: Journal of Harbin Institute of Technology (New Series), v 14, n SUPPL., January, 2007, p 63-66

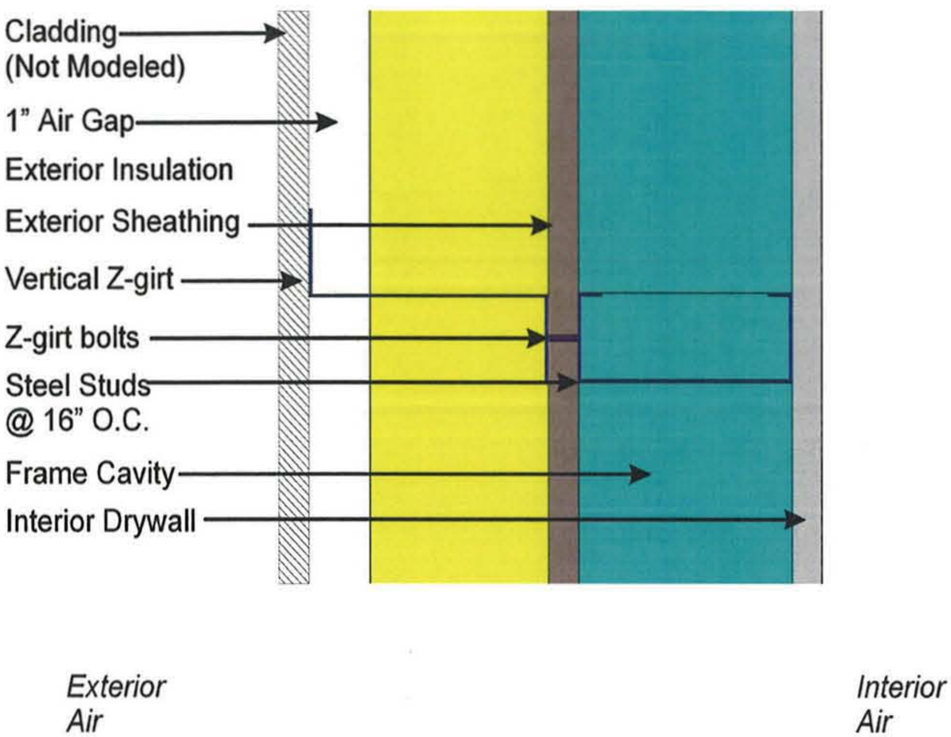
Thermal Insulation and Thermal Bridge of Steel-Framed Walls. Suda, Noriyuki (technical Development Bur); Uno, Nobuyoshi; Shimizu, Jun; Kanno, Ryoichi; Sugita, Koji. Source: Nippon Steel Technical Report, n 79, Jan, 1999, p 35-40

APPENDIX A

MH Standard Procedure to Calculate U-value using a Heat Transfer Computer Model (THERM): Standard Steel Stud Wall Assembly

Description: Vertical Z-girts Connected to Interior Steel Studs

Modeled Section:



Boundary Conditions:

Convection
Film Coefficients:
Interior: 8.30 W/m^2 K
Exterior: 8.30 W/m^2 K

Air Temperature
Interior: 21°C
Exterior: -5°C

Radiation Model
Interior: Auto Enclosure
Ti = 21°C
Ei = 0.9
Exterior: Blackbody
Ti = -5°C
Ei = 0.9
View Factor = 1

Assumptions:

1. Effective conductivity of Z-girt bolt connection.

Effective conductivity of the section containing z-girt bolts was based on ¼" bolts 16" o.c. using the following equation (see THERM manual, p. 8-68):

$$K_{eff} = K_b \cdot F_b + K_s \cdot F_s$$

Where

K_b = conductivity of steel bolt, 62 W/m-K;

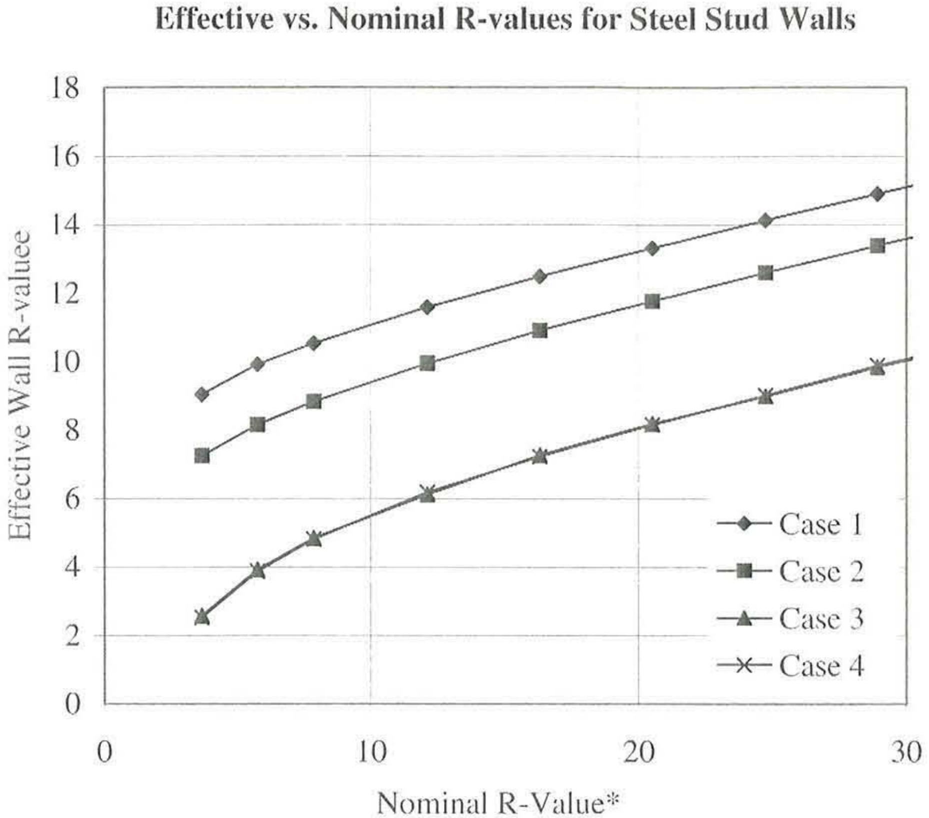
K_s = conductivity of sheathing, 0.17 W/m-K;

F_b = fraction of steel area in section, 0.25" / 16" = 0.0156;

F_s = fraction of sheathing in the section, 23.75" / 16" = 0.9844;

K_{eff} = effective conductivity of the section, 1.14 W/m-K.

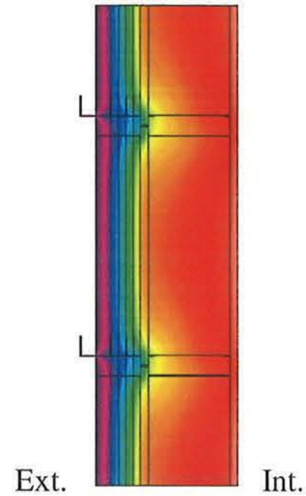
2. Exterior cladding not included in model.
3. 2-D horizontal cross section.



Modeled Wall Section and Typical Heat Flow Path of Steel Thermal Bridges (No Batt Insulation):

Model:

Results: Heat Flow Path



*Nominal R-value of exterior insulation + R3.7 provided by the wall structure.

Modeled Cases:

Case 1: 5½" Framing with Fiberglass Batt Insulation (R20) in Stud Cavity

Case 2: 3½" Framing with Fiberglass Batt Insulation (R12) in Stud Cavity

Case 3: 140mm (5½") Framing, Empty Stud Cavity

Case 4: 90mm (3½") Framing, Empty Stud Cavity

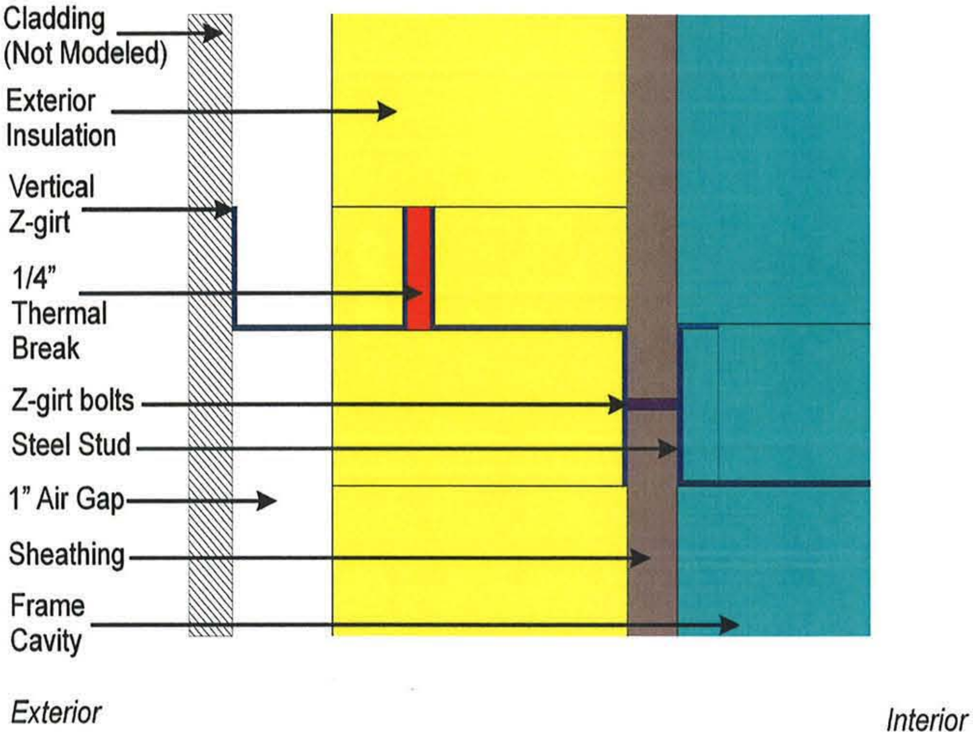
Conclusions:

- Exterior insulation with a nominal resistance of R20 or R12 provides effective R-values of R6.5 and R4.5, respectively. In comparison, the addition of batt insulation to the stud cavity increases the overall wall R-value by roughly R6 and R4 for R20 and R12 batt insulation, respectively. This corresponds to approximately a 35% effectiveness of the exterior insulation, as compared to 30% for the batt insulation.
- For no insulation in the steel stud cavity, the size of the cavity (ie. 3.5" or 5.5" stud framing) has essentially no effect on the modeled thermal resistance of the wall assembly. (Cases 3 and 4 in the plot above are superimposed on one another.)

MH Standard Procedure to Calculate U-value using a Heat Transfer Computer Model (THERM): Thermally Broken Vertical Z-girts

Figure 1: Thermal Break in Perpendicular Orientation

Modeled Section:



Boundary Conditions:

Convection Film Coefficients:

Interior: 8.30 $W/m^2 K$

Exterior: 8.30 $W/m^2 K$

Air Temperature

Interior: 21°C

Exterior: -5°C

Radiation Model

Interior: Auto Enclosure

Ti = 21°C

Ei = 0.9

Exterior: Blackbody

Ti = -5°C

Ei = 0.9

View Factor = 1

Assumptions:

1. Effective conductivity of Z-girt bolt connection.

Effective conductivity of the section containing z-girt bolts was based on ¼" bolts 16" o.c. using the following equation (see THERM manual, p. 8-68):

$$K_{eff} = K_b \cdot F_b + K_s \cdot F_s$$

Where

K_b = conductivity of steel bolt, 62 W/m-K;

K_s = conductivity of sheathing, 0.17 W/m-K;

F_b = fraction of steel area in section, 0.25" / 16" = 0.0156;

F_s = fraction of sheathing in the section, 23.75" / 16" = 0.9844;

K_{eff} = effective conductivity of the section, <u>1.14 W/m-K.</u>

2. Exterior cladding not included in model.
3. 2-D horizontal cross section.

Assumptions (cont.):

4. Effective conductivity of the thermal break connection.

In the model, the thermal break was composed of three separate materials in the section shown in Figure 1. Modeling was done in two stages. First, the model was run with the thermal break as pure airspace, and then the model was re-run with the thermal break composed purely of material having an effective conductivity based on 1" x 1" nylon and a 3/16" screw. The final effective R-value was found as the weighted average of the R-values of the two models just mentioned. See below for the calculation of the effective conductivity of the nylon spacer and screw:

$$K_{eff} = K_{ny} \cdot F_{ny} + K_s \cdot F_s$$

Where

K_{ny} = conductivity of nylon, 0.25 W/m-K;

K_s = conductivity of steel bolt, 62 W/m-K;

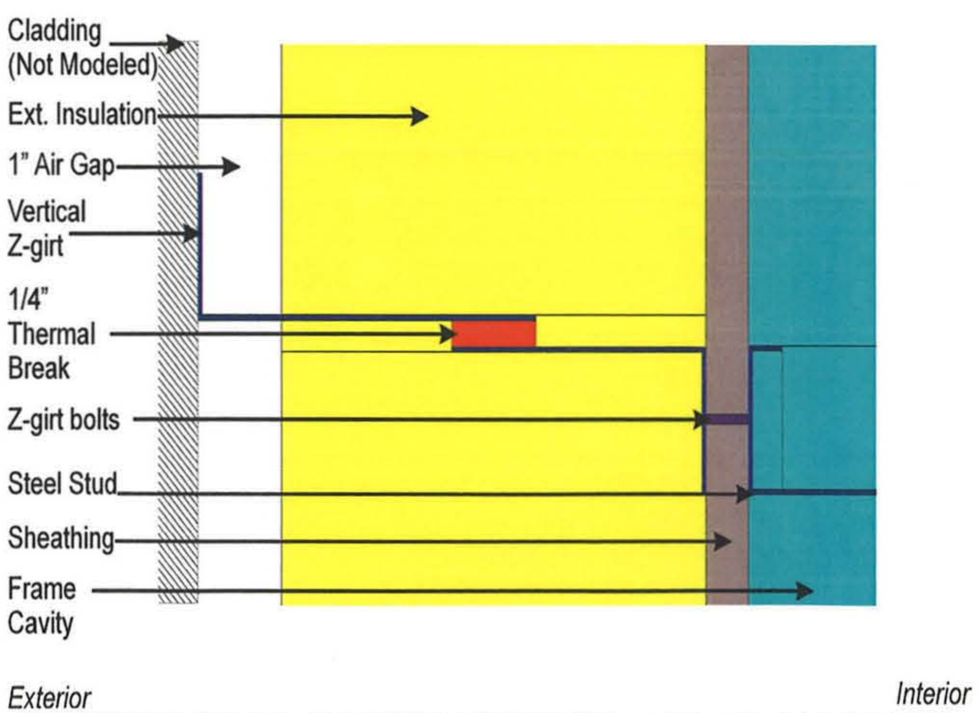
F_s = fraction of steel area in the spacer section, (π * (3 / 32) ^2) / 1 = 0.0276;

F_{ny} = fraction of nylon in the spacer section, (1 - 0.0276) / 1 = 0.9724;

K_{eff} = 0.25 * .9724 + 62 * 0.0276 = 1.95.

Figure 2: Thermal Break in Parallel Orientation

Modeled Section:



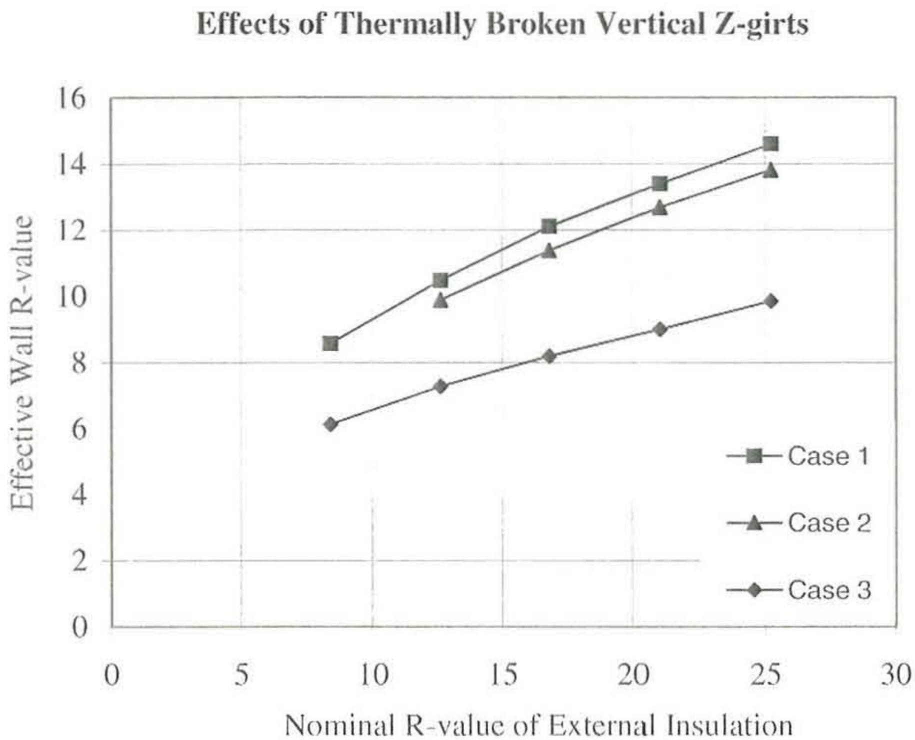
Boundary Conditions:

Convection Film Coefficients:
Interior: 8.30 W/m^2K
Exterior: 8.30 W/m^2K

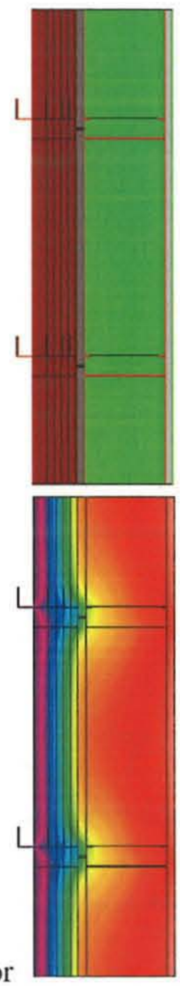
Air Temperature
Interior: 21°C
Exterior: -5°C

Radiation Model
Interior: Auto Enclosure
Ti = 21°C
Ei = 0.9
Exterior: Blackbody
Ti = -5°C
Ei = 0.9
View Factor = 1

Figure 3: Thermally Broken Z-girts (No Batt Insulation)



Modeled Wall Section and Typical Heat Flow Path of Steel Thermal Bridges:



Modeled Cases:

Case 1: ¼" thermal break as in Figure 1; made of airspace, plus 3/16" screws and nylon spacers at 12" O.C.

Case 2: ¼" thermal break as in Figure 2; made of airspace, plus 3/16" screws and nylon spacers at 12" O.C.

Case 3: Regular vertical Z-girts (no thermal breaks).

Modeling Procedure:

- The case of thermally broken vertical Z-girts was modeled as follows: The Z-girts were "cut" lengthwise, then bolted back together with 1" x 1" x ¼" thick nylon spacers (fastened by 3/16" screws) at 12" O.C. The width of the overlapping region was modeled as 1" (see Figures 2 & 3). The thermal break provides about a 39% gain in overall wall R-value over standard vertical Z-girts.

- The thermal break was also modeled in a perpendicular orientation designed to further reduce thermal bridging. This configuration offers a gain of about 46% over standard vertical Z-girts in overall wall R-value. Refer to Figures 1 & 3.

Notes:

- Modeling was done with the thermal break located at or about halfway through the depth of the exterior insulation. Edge testing was completed to find the impact of having the thermal break located nearer the outer edge of the insulation. This testing showed that the location of the thermal break has an impact, but the optimum location was not determined.

- The case of a thermal break was not modeled for exterior insulation thicknesses of less than two inches.

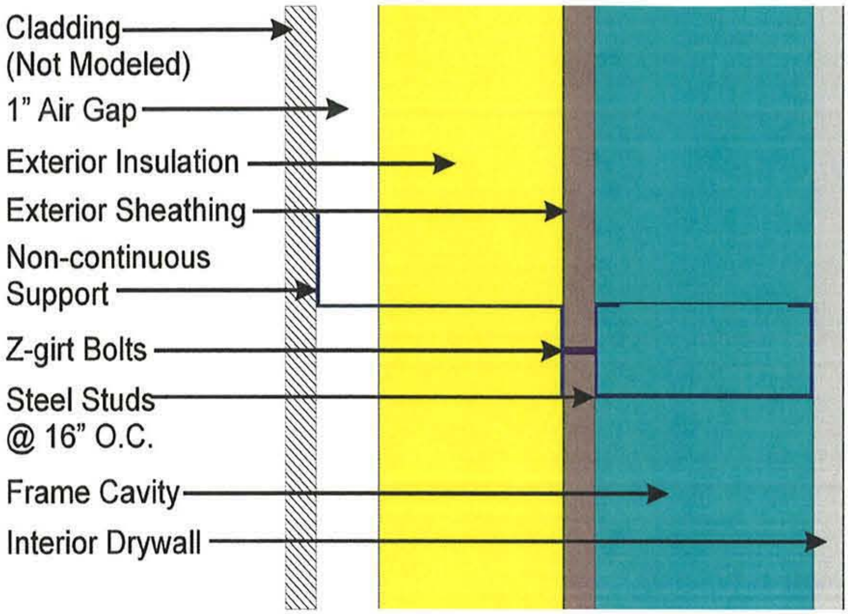
Conclusions:

- Significant gains in effective R-value can be achieved through the use of Z-girts containing a thermal break, and thermal bridging is even further reduced by having the thermal break lie in an orientation perpendicular to the Z-girt. The increase in effective wall R-value associated with the use of thermally broken vertical Z-girts is in the range of a 40% to 45% improvement over standard vertical Z-girts.

MH Standard Procedure to Calculate U-value using a Heat Transfer Computer Model (THERM): Non-continuous Cladding Supports

Figure 1: Non-continuous Vertical Z-girts

Modeled Section:



Boundary Conditions:

Convection Film Coefficients:
Interior: 8.30 W/m^2K
Exterior: 8.30 W/m^2K

Air Temperature
Interior: 21°C
Exterior: -5°C

Radiation Model
Interior: Auto Enclosure
Ti = 21°C
Ei = 0.9
Exterior: Blackbody
Ti = -5°C
Ei = 0.9
View Factor = 1

Assumptions:

1. Effective conductivity of Z-girt bolt connection.

Effective conductivity of the section containing z-girt bolts was based on ¼" bolts 16" o.c. using the following equation (see THERM manual, p. 8-68):

$$K_{eff} = K_b \cdot F_b + K_s \cdot F_s$$

Where

K_b = conductivity of steel bolt, 62 W/m-K;

K_s = conductivity of sheathing, 0.17 W/m-K;

F_b = fraction of steel area in section, 0.25" / 16" = 0.0156;

F_s = fraction of sheathing in the section, 23.75" / 16" = 0.9844;

K_{eff} = effective conductivity of the section, <u>1.14 W/m-K.</u>

2. Exterior cladding not included in model.
3. 2-D horizontal cross section.

Assumptions (cont.):

4. Effective Conductivities Used for Modeling Intermittent Supports

Intermittent supports were modeled as 1.1mm wide (18 gauge) steel spaced 16" O.C. (In a horizontal cross-section - essentially as intermittently spaced sections of vertical z-girt) The percentage of z-girt remaining was varied from 1% to 100% (regular Z-girts).

Example Calculation for the case of 75% of the Z-girt remaining (Equation from THERM manual, p. 8-68):

$$K_{eff} = K_{ins} \cdot F_{ins} + K_s \cdot F_s$$

Where

Error! Objects cannot be created from editing field codes.= conductivity of insulation, 0.0343 W/m-K;

K_s = conductivity of steel, 62 W/m-K;

Error! Objects cannot be created from editing field codes.= fraction of steel removed from the z-girt section, 0.25;

F_s = fraction of steel remaining in the z-girt section, 0.75;

K_{eff} = 0.0343* 0.25 + 62 * 0.75 = <u>46.509.</u>

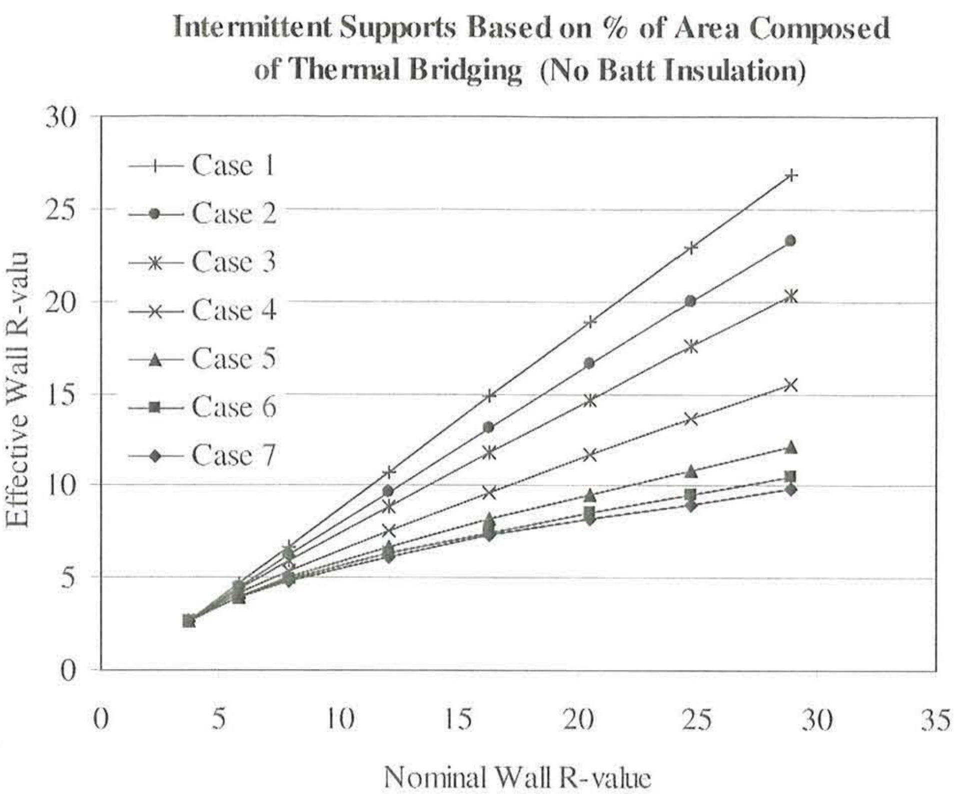
Results are tabulated below:

% z-girt remaining	% of wall area penetrated by steel	effective K-value used for modeling (W/m-K)
100	0.2707	62
75	0.203	46.509
50	0.1353	31.017
25	0.06767	15.526
10	0.02707	6.2309
5	0.01353	3.1326
1	0.002707	0.654

Procedure:

- Intermittent supports (fastened at studs) were modeled as vertical Z-girts with sections intermittently removed from them, and modeling was based on percentages of thermal bridging (steel) per unit area of exterior wall surface. Modeling was completed in a horizontal section, by assigning a range of effective conductivities to the non-continuous support in the figure above. The range of effective conductivities used was based directly on the percentage of vertical Z-girt remaining after the removal of intermittent sections, varying from 100% (regular z-girts) to 1% of the steel of a regular Z-girt remaining. Conclusions and modeled data are shown below.

Figure 2: Comparison of Hybrid Z-girts to Horizontal and Vertical Z-girts



Modeled Cases:

Case 1: 0.002707% of wall area penetrated by steel

Case 2: 0.01353% of wall area penetrated by steel

Case 3: 0.02707% of wall area penetrated by steel

Case 4: 0.06767% of wall area penetrated by steel

Case 5: 0.1353% of wall area penetrated by steel

Case 6: 0.203% of wall area penetrated by steel

Case 7: 0.2707% of wall area penetrated by steel

Modeled Wall Section and Typical Heat Flow Path of Steel Thermal Bridges (No Batt Insulation):

Model:

Results: Heat Flow Path

Ext.  Int.

Conclusions:

- As can be seen from the graph above, the greater the reduction in thermal bridging, the more dramatically the effective R-value of the wall increases. Furthermore, the above results are calculated on the assumption that intermittent supports are fastened at studs: fastening them at points between studs would further increase thermal gains. Please refer to Figures 3-5 below for tabulated data.

Figure 3:

Summary table for intermittent vertical z-girts (No Batt Insulation)							
% regular Z-girt:	100	75	50	25	10	5	1
% of wall composed of steel bridging:	0.2707	0.203	0.1353	0.06767	0.02707	0.01353	0.002707
Nominal Wall R-Value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value
28.92	9.84	10.49	12.10	15.48	20.27	23.23	26.78
24.72	8.98	9.54	10.85	13.61	17.53	19.97	22.94
20.51	8.18	8.53	9.54	11.65	14.67	16.55	18.88
16.31	7.27	7.46	8.16	9.65	11.77	13.12	14.83
12.11	6.12	6.28	6.70	7.57	8.83	9.64	10.70
7.90	4.84	4.86	5.03	5.38	5.89	6.23	6.69
5.80	3.92	3.91	3.98	4.12	4.32	4.45	4.65
3.70	2.57	2.57	2.57	2.58	2.60	2.60	2.62

Figure 4:

Summary table for intermittent vertical z-girts (5.5" Insulated Frame Cavity)							
% regular Z-girt:	100	75	50	25	10	5	1
% of wall composed of steel bridging:	0.2707	0.203	0.1353	0.06767	0.02707	0.01353	0.002707
Nominal Wall R-Value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value
45.84	14.89	15.66	17.39	21.05	26.68	30.36	35.01
41.63	14.12	14.73	16.14	19.16	23.87	26.99	30.98
37.43	13.31	13.75	14.87	17.25	21.04	23.58	26.91
33.22	12.47	12.75	13.58	15.41	18.18	20.14	22.82
29.02	11.58	11.72	12.27	13.49	15.34	16.72	18.70
24.81	10.53	10.56	10.85	11.50	12.53	13.29	14.40
22.71	9.92	9.91	10.08	10.45	11.03	11.45	12.15
20.61	9.03	8.98	9.02	9.11	9.22	9.29	9.41

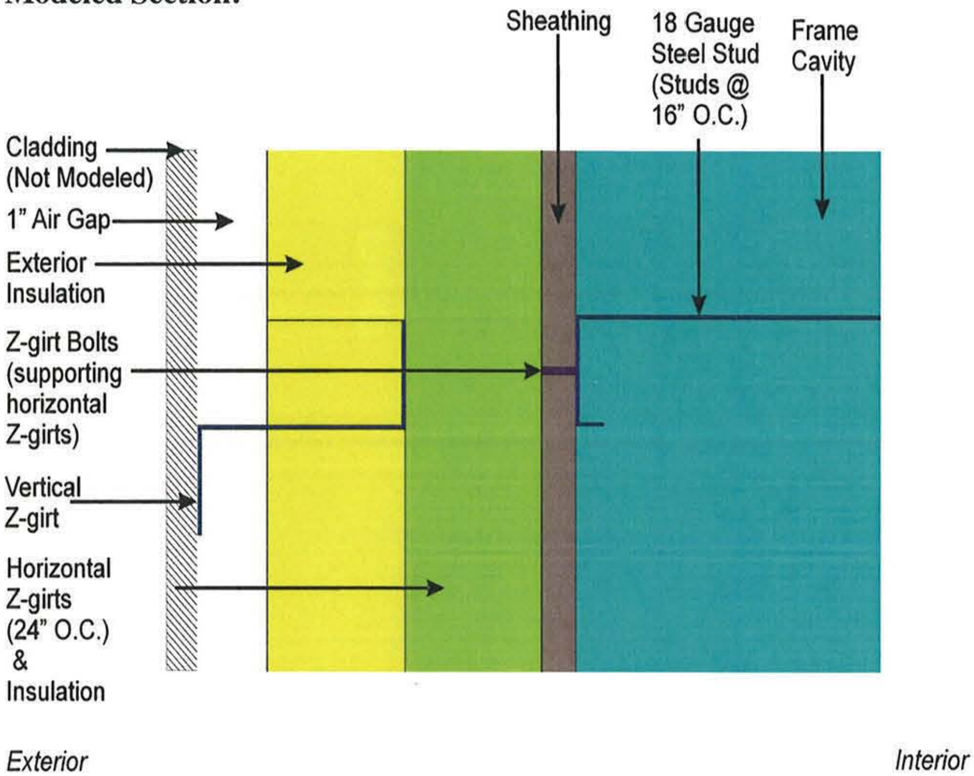
Figure 5:

Summary table for intermittent vertical z-girts (3.5" Insulated Frame Cavity)							
% regular Z-girt:	100	75	50	25	10	5	1
% of wall composed of steel bridging:	0.2707	0.203	0.1353	0.06767	0.02707	0.01353	0.002707
Nominal Wall R-Value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value	Effective R-value
36.98	13.38	14.12	15.79	19.33	24.75	28.26	32.69
32.78	12.58	13.16	14.53	17.41	21.91	24.86	28.63
28.57	11.77	12.18	13.25	15.51	19.08	21.47	24.58
24.37	10.89	11.16	11.94	13.65	16.23	18.06	20.52
20.16	9.94	10.07	10.58	11.70	13.39	14.63	16.42
15.96	8.83	8.86	9.11	9.68	10.59	11.25	12.22
13.85	8.16	8.15	8.29	8.60	9.10	9.46	10.04
11.75	7.24	7.20	7.23	7.30	7.39	7.45	7.54

MH Standard Procedure to Calculate U-value using a Heat Transfer Computer Model (THERM): Combined Horizontal and Vertical Z-girts

Figure 1: Combined Horizontal and Vertical Z-girts

Modeled Section:



Boundary Conditions:

Convection
Film Coefficients:
Interior: 8.30 W/m^2K
Exterior: 8.30 W/m^2K

Air Temperature
Interior: 21°C
Exterior: -5°C

Radiation Model
Interior: Auto Enclosure
Ti = 21°C
Ei = 0.9
Exterior: Blackbody
Ti = -5°C
Ei = 0.9
View Factor = 1

Assumptions:

1. Effective conductivity of Z-girt bolt connection.

Effective conductivity of the section containing z-girt bolts was based on ¼" bolts 16" o.c. using the following equation (see THERM manual, p. 8-68):

$$K_{eff} = K_b \cdot F_b + K_s \cdot F_s$$

Where

K_b = conductivity of steel bolt, 62 W/m-K;

K_s = conductivity of sheathing, 0.17 W/m-K;

F_b = fraction of steel area in section, 0.25" / 16" = 0.0156;

F_s = fraction of sheathing in the section, 23.75" / 16" = 0.9844;

K_{eff} = effective conductivity of the section, <u>1.14 W/m-K.</u>

2. Exterior cladding not included in model.
3. 2-D horizontal cross section.

Assumptions (cont.):

4. Effective conductivity of region containing horizontal z-girts

Since modeling was completed in a horizontal section, the thermal bridging of the horizontal Z-girts through the exterior insulation was modeled using an effective conductivity. This had to be done since the thermal bridging of the horizontal Z-girts is not in the same plane as the bridging of the steel studs. The effective conductivity for this representative material was determined through a trial and error method using THERM, according to the procedure below:

1. The wall was modeled in a vertical cross-section containing all materials (except studs), and an effective R-value was found.

2. Horizontal Z-girts and insulation were replaced with a single representative material having an "guessed" effective K-value.

3. The section was then repeatedly modeled with different effective K-values, until an effective conductivity was found which yielded the same R-value for the entire wall assembly as when the true thermal bridging was modeled.

4. The effective K-value tends to vary with the depth of insulation, and therefore curves of effective conductivity versus insulation depth were constructed.

It should be noted that effective conductivities can be calculated as the weighted averages of the conductivities of individual materials. However, in cases where the conductivities of the materials vary greatly from each other and the materials occupy a significant fraction of the model (as with steel and insulation), this method can be a large approximation of bridging effects. Comparison of the weighted averages method and the above procedure showed that conductivities calculated by the above procedure yield more accurate results.

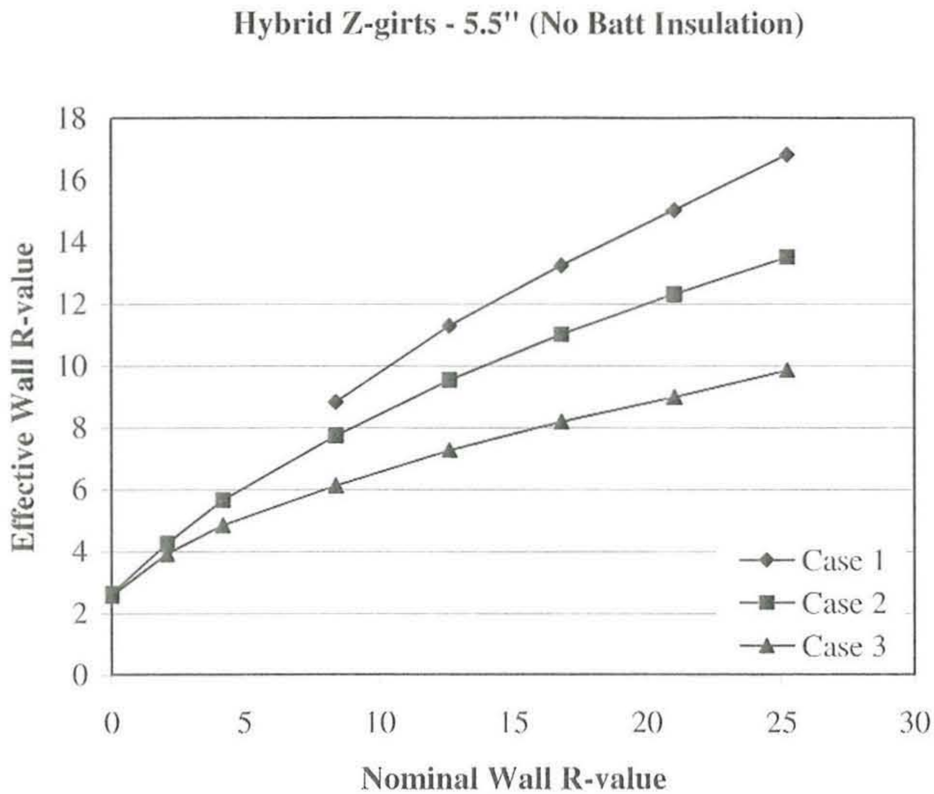
Additional Notes:

- The depths of the vertical Z-girt and horizontal Z-girt layers were maintained as close as possible to being equal. The THERM model used has exterior insulation in half-inch layers, so for some depths of insulation modeled, the horizontal Z-girt layer was thicker than the vertical layer.

- Some edge testing done indicated that optimum effective R-value is achieved by having the horizontal Z-girt layer somewhat thicker than the vertical Z-girt layer. However, modeling was not completed comprehensively enough to indicate the optimum ratio of horizontal to vertical Z-girt layer depths, so results are based on a 1:1 ratio. This was done since the variances in effective R-value based on adjusting the depth ratio were not significantly large in any case modeled.

- Modeling was not done for overall insulation depths of less than 2 inches.

Figure 2: Comparison of Hybrid Z-girts to Horizontal and Vertical Z-girts



Modeled Cases:

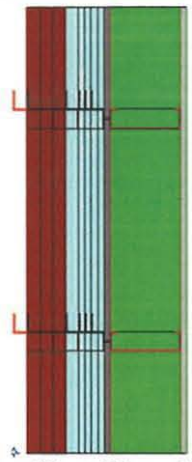
Case 1: Hybrid Horizontal and Vertical Z-girts.

Case 2: Horizontal Z-girts.

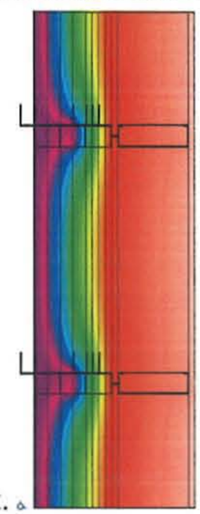
Case 3: Vertical Z-girts.

Modeled Wall Section and Typical Heat Flow Path of Steel Thermal Bridges (No Batt Insulation):

Model:



Results: Heat Flow Path



Ext. Int.

Conclusions:

- The use of vertical Z-girts atop a layer of horizontal Z-girts produces significant gains in thermal performance over both vertical and horizontal Z-girts systems, due to the large reduction in thermal bridging. This configuration offers a gain of about 60% over regular Z-girts in overall wall R-value.