The Building Envelope Thermal Bridging Guide

October 16, 2014
Presentation Overview

1. Overview of the Thermal Bridging Guide
2. Significance and Insights
3. Where Next?
Acknowledgments

Main Authors

Patrick Roppel, Principal, Building Science Specialist
Christian Cianfrone, Principal, Building Energy Specialist
Neil Norris, Building Energy Consultant

Building Performance Analysis Group

Ivan Lee, Building Science Consultant
Ruth McClung, Building Science Consultant
Nick Adamson, Building Science Consultant
Radu Postale, Building Science Consultant
Alex Blue, Building Energy Consultant

Advisors

Mark Lawton, VP, Senior Building Science Specialist
Jameson Vong, Principal, Building Envelope Specialist
Eileen Holt, Business Development Coordinator
Funding Partners

BC hydro
dowersmart

FORTIS BC

FP Innovations

Canadian Wood Council

Conseil canadien du bois

Homeowner Protection Office
Branch of BC Housing
Private Clients

• EIFS
• Insulated Metal Panel
• Cladding attachments
• Vacuum insulated panels (VIP) in insulated glazed units for glazing spandrel sections
• Structural thermal breaks manufacturer
Use of Energy Codes

- Code Compliance in all of BC
  - References either ASHRAE 90.1 2010 or NECB 2011
- LEED
  - References either ASHRAE 90.1 2007 or MNECB 1997
  - Requires “better than” minimum performance
  - Modeling procedures and assumptions differ from Code compliance – see LEED documents!
- Incentive Programs
  i.e. BC Hydro New Construction Program
  - References ASHRAE and NECB, with modifications
  - Modeling procedures and rules published by BC Hydro
## ASHRAE 90.1 Prescriptive Opaque Opaque areas

<table>
<thead>
<tr>
<th>Components</th>
<th>Zone 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Residential</td>
</tr>
<tr>
<td></td>
<td>U factor</td>
</tr>
<tr>
<td>Roof - insulation above deck</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>(R20.8)</td>
</tr>
<tr>
<td>Roof - Attic</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>(R37.0)</td>
</tr>
<tr>
<td>Walls - Mass</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>(R14.1)</td>
</tr>
<tr>
<td>Walls - Steel framed</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td>(R15.6)</td>
</tr>
<tr>
<td>Walls - Wood framed</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>(R19.6)</td>
</tr>
</tbody>
</table>
Effective Thermal Resistance

What is a Thermal Bridge?

- Highly conductive material that by-passes insulation layer
- Areas of high heat transfer
- Can greatly affect the thermal performance of assemblies
• Calculate **thermal performance data** for common building **envelope details** for mid- and high-rise construction

• Develop **procedures** and a **catalogue** that will allow designers quick and straightforward access to information

• Provide information to answer the fundamental questions of how overall geometry and materials affect the overall thermal performance
ASHRAE Research Project

Calibrated 3D Modeling Software

- Heat transfer software by Siemens PLM Software, FEMAP & Nx
- Model and techniques calibrated and validated against measured and analytical solutions
- ISO Standards for glazing
- Guarded hot box test measurements, 29 in total
ASHRAE Research Project

- **40 building assemblies** and details common to North American construction
- Focus on opaque assemblies, but also includes some glazing transitions
- Details not already addressed in ASHRAE publications
- Highest priority on details with thermal bridges in 3D
What’s this BC Study?

Building Envelope Thermal Bridging Guide
Analysis, Applications, & Insights
1365-RP and Beyond

• Connected the dots
NEW CONSTRUCTION PROGRAM

INCENTIVES, RESOURCES

Power Smart offers financial incentives, resources and technical assistance to building owners, developers and the design industry to create high-performance, energy-efficient buildings.

What it looks like: featured projects

Incentives to study system design
Building Envelope Thermal Bridging Guide

This guide explores how the building industry in British Columbia can meet the challenges of reducing energy use in buildings, in part by effectively accounting for the impact of thermal bridging.

Most practitioners will find PART 1 and Appendices A and B to be most useful. PART 1 outlines how to effectively account for thermal bridging. Appendices A and B provide a catalog of common building envelope assemblies and interface details, and their associated thermal performance data.

Researchers and regulators will be interested in PART 2 and PART 3, and Appendices C to E. They contain the cost-benefit analysis, and discussion on significance and further insights, of using this guide to mitigate thermal bridging in buildings.

- Introduction [PDF, 2.2 MB]
- Part 1: Building Envelope Thermal Analysis (BETA) Guide [PDF, 4.5 MB]
- Part 2: Energy Savings and Cost Benefit Analysis [PDF, 1.8 MB]
- Part 3: Significance, Insights and Next Steps [PDF, 2.8 MB]
- Appendix A – Catalogue Material Data Sheets [PDF, 14.3 MB]
- Appendix B – Catalogue Thermal Data Sheets [PDF, 11.7 MB]
- Appendix C – Energy Modeling Analysis and Results [PDF, 1.2 MB]
- Appendix D – Construction Costs [PDF, 1.2 MB]
- Appendix E – Cost Benefit Analysis [PDF, 7.3 MB]
The Beginning of Guides

- Introduction
- Part 1 Building Envelope Thermal Analysis (BETA) Guide
- Part 2 Energy and Cost Analysis
- Part 3 Significance, Insights, and Next Steps
- Appendix A Material Data Catalogue
- Appendix B Thermal Data Catalogue
- Appendix C Energy Modeling Analysis and Results
- Appendix D Construction Costs
- Appendix E Cost Benefit Analysis
And now for a little math
Parallel Path Heat flow

- Assumes heat flows are separate and do not influence each other
- Averages overall heat flow/resistance based on the areas of components

\[
U_{total} = \left( \frac{U_1A_1 + U_2A_2 + U_3A_3 \ldots}{A_1 + A_2 + A_3 \ldots} \right) \cdot \Delta T
\]
\[
\frac{1}{R} = \frac{0.75 \times 1/2 + 8.25 \times 1/20}{0.75 + 8.25}
\]

\[ R \approx 11.5 \]
Thermal Bridging

- Parallel path doesn’t tell the whole story
- Many thermal bridges don’t abide by “areas” i.e.: shelf angle
- Lateral heat flow can greatly affect the thermal performance of assemblies
Addressing lateral Heat Flow
Overall Heat Loss

\[ Q = Q_o - Q_{slab} \]

Additional heat loss due to the slab
The linear transmittance represents the additional heat flow because of the slab, but with area set to zero.
The Conceptual Leap

Types of Transmittances

- Clear Field: $U_o$
- Linear: $\Psi$
- Point: $\chi$
Overall Heat Loss

Total Heat loss = heat loss due to clear field + Heat loss due to anomalies

\[
\frac{Q}{\Delta T} = \sum(U_o \cdot A) + \sum(\Psi \cdot L) + \sum(\chi)
\]
Identifying assemblies and details

1. Concrete Clear Wall
2. Parapet
3. Flush Slab
4. Balcony Slab
5. Window Transition
### Summing Transmittances

<table>
<thead>
<tr>
<th>Transmittance Description</th>
<th>Area, Length or Amount</th>
<th>Units</th>
<th>Transmittance Value</th>
<th>Units</th>
<th>Source Ref</th>
<th>Heat Flow BTU/hr°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazed Spandrel</td>
<td>9036</td>
<td>ft²</td>
<td>0.13</td>
<td>ft²/°F</td>
<td>1.1.1</td>
<td>1,175</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1365-18</td>
</tr>
<tr>
<td>Parapet at Window Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1.5</td>
</tr>
<tr>
<td>Parapet at Concrete Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1365-20</td>
</tr>
<tr>
<td>Parapet and WW to Deck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1.5</td>
</tr>
<tr>
<td>Parapet at Con Wall to Deck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1365-20</td>
</tr>
<tr>
<td>Glazing Transition, Vert.</td>
<td>19938</td>
<td>ft</td>
<td>0.29</td>
<td>ft/°F</td>
<td>4.1</td>
<td>5,782</td>
</tr>
<tr>
<td>Glazing Transition, Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.2</td>
<td>704</td>
</tr>
<tr>
<td>Balcony at WW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.2</td>
<td>1,254</td>
</tr>
<tr>
<td>Balcony at Conc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1365-18</td>
<td>835</td>
</tr>
<tr>
<td>Spandrel Bypass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1.3</td>
<td>1,041</td>
</tr>
<tr>
<td>Eyebrow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.1</td>
<td>444</td>
</tr>
<tr>
<td>Shear Wall</td>
<td>1295</td>
<td>ft</td>
<td>0.66</td>
<td>ft/°F</td>
<td>3.4</td>
<td>855</td>
</tr>
</tbody>
</table>

**Opaque U-Value (BTU/hr ft² °F)**

- Glazed Spandrel: 0.080
- Balcony at WW: 0.280

**Effective R-value (ft² hr °F/BTU)**

- Glazed Spandrel: 12.5
- Balcony at WW: 3.6
CLADDING ATTACHMENTS

- Vertical Z-Girts
- Horizontal Z-Girts
- Mixed Z-Girts
- Intermittent Z-Girts
Clip Systems
Effect of Thermal bridging in 3D

Graph showing the relationship between Effective R-Value of Assembly and Exterior Insulation Nominal (1D) R-Value for different assembly types:
- Continuous Vertical Girts
- Continuous Vertical/Horizontal Girts
- Vertical Steel Clip and Sub-girt @ 36" o.c.
- Continuous Insulation
- Continuous Horizontal Girts
- Vertical Steel Clip @ 24" o.c.
- Horizontal Steel Clip and Sub-girt @ 24" o.c.

Comparisons are made between NECB 2011 and ASHRAE 90.1 2010 standards.
Glazing Spandrel Areas

Curtain Wall Comparison

Spray Foam
Glazing Spandrel Areas

![Graph showing the relationship between back pan insulation and spandrel section R value. The graph compares two details:
- Detail 22 (Air in Stud Cavity)
- Detail 23 (Spray Foam in Stud Cavity)

The graph indicates that as back pan insulation increases, the spandrel section R value also increases for both details. Details 22 and 23 show different performance levels, with Detail 23 generally having a higher R value.](image-url)
Glazing Spandrel Areas

No Spray Foam

Spray Foam
Concrete Walls

Think about it!
An R10 wall would have a transmittance of 0.1 BTU/hr-ft²•°F.
One linear foot of this detail is the same as 4.7 ft² of R10 wall (or 7.3 ft² of R15.6 wall).

Parallel Path

Linear Transmittance

$R \approx 11.5$

$R \approx 9.8$
Concrete Walls
Slab Edges – Balcony

<table>
<thead>
<tr>
<th></th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ψ</td>
<td>0.59</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Slab Edges – Shelf Angle

<table>
<thead>
<tr>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.47</td>
<td>0.27</td>
</tr>
</tbody>
</table>

AVERAGE => POOR
Slab Edges – Shelf Angle

<table>
<thead>
<tr>
<th></th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ψ</td>
<td>0.31</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Slab Edges – Balcony

Thermally Broken Balcony Slab

<table>
<thead>
<tr>
<th></th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Psi$</td>
<td>0.21</td>
<td>0.12</td>
</tr>
</tbody>
</table>
With EIFS

<table>
<thead>
<tr>
<th>Assembly Type</th>
<th>Exterior Insulation Nominal R-Value</th>
<th>Linear Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Stud wall with EIFS</td>
<td>R-15 (2.64)</td>
<td>0.012 (0.022)</td>
</tr>
<tr>
<td>Steel Stud with EIFS and R-12 batt insulation in stud cavity</td>
<td>R-7.5 (1.32)</td>
<td>0.076 (0.132)</td>
</tr>
<tr>
<td>Pour-in-place concrete wall with EIFS</td>
<td>R-15 (2.64)</td>
<td>0.013 (0.023)</td>
</tr>
</tbody>
</table>
**Window Interface**

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Description and Examples</th>
<th>Linear Transmittance</th>
</tr>
</thead>
</table>
| **Efficient**        | Well aligned glazing without conductive bypasses  
Example: wall insulation is aligned with the glazing thermal break. Flashing does not bypass the thermal break.  
The EIFS interface with the curtain wall was in this category. | 0.1 | 0.17 |
| **Regular**          | Misaligned glazing and minor conductive bypasses  
Examples: wall insulation is not continuous to thermal break.  
The EIFS punched window details, without improvements, are in this category. | 0.2 | 0.35 |
| **Poor**             | Un-insulated and conductive bypasses  
Examples: metal closures connected to structural framing. Un-insulated concrete opening (wall insulation ends at edge of opening). | 0.3 | 0.5 |
Window in Wall with Ext. Insulation - Empty Cavity

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Plywood Liner</th>
<th>Plywood Liner with Window at Exterior</th>
<th>R-4 Insulation Wrapped into Opening</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linear Transmittance (W/m K)</strong></td>
<td>0.41</td>
<td>0.24</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Glass Temperature Index at Edge (-)</strong></td>
<td>0.465</td>
<td>0.464</td>
<td>0.460</td>
<td>0.456</td>
</tr>
<tr>
<td><strong>Frame Temperature Index (-)</strong></td>
<td>0.503</td>
<td>0.505</td>
<td>0.499</td>
<td>0.485</td>
</tr>
</tbody>
</table>
Point

χ
# Beam Thermal Breaks

<table>
<thead>
<tr>
<th></th>
<th>Exterior Insulation 1D R-Value (RSI)</th>
<th>$R_0$ (ft$^2$·hr·°F / Btu (m$^2$ K / W))</th>
<th>$R_{\text{effective}}$ (ft$^2$·hr·°F / Btu (m$^2$ K / W))</th>
<th>$\Psi$ (Btu/ft hr °F (W/m K))</th>
<th>Minimum Temperature Index on slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Beam</td>
<td>R-27 (4.79)</td>
<td>R-17 (3.04)</td>
<td>R-7 (1.19)</td>
<td>1.73 (0.92)</td>
<td>0.483</td>
</tr>
<tr>
<td>With Isokorb® type S</td>
<td>R-27 (4.79)</td>
<td>R-17 (3.04)</td>
<td>R-9 (1.61)</td>
<td>0.91 (0.48)</td>
<td>0.749</td>
</tr>
</tbody>
</table>
Insights
The impact depends on type of construction.

- Heat flow associated with details
- Heat flow associated with clear field assembly

<table>
<thead>
<tr>
<th></th>
<th>R-10.1 &quot;Effective&quot;</th>
<th>R-6.7 &quot;Effective&quot;</th>
<th>R-3.9 &quot;Effective&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood-frame with R-19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity Insulation</td>
<td>394</td>
<td>749</td>
<td>1530</td>
</tr>
<tr>
<td></td>
<td>422</td>
<td>509</td>
<td>611</td>
</tr>
</tbody>
</table>

53 Cavity Insulation

Steel-frame with R-10 Exterior and R-12 Cavity Insulation

Concrete with R-10 Interior Insulation
We Ain’t Building What We Think We are Building
Thermal bridges at transitions not captured by ASHRAE wall assumptions
Just Adding Insulation is Seldom Effective

Adding More Insulation to Steel Stud Assemblies to go from an “Effective” R-value of R-15.6 to R-20

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Incremental Construction Cost</th>
<th>Energy Cost Savings</th>
<th>Payback (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Office</td>
<td>$94,825</td>
<td>$1,116</td>
<td>85</td>
</tr>
<tr>
<td>High-Rise MURB</td>
<td>$153,222</td>
<td>$2,542</td>
<td>60</td>
</tr>
<tr>
<td>Hotel</td>
<td>$64,650</td>
<td>$543</td>
<td>119</td>
</tr>
<tr>
<td>Large Institutional</td>
<td>$150,375</td>
<td>$1,833</td>
<td>82</td>
</tr>
<tr>
<td>Non-Food Retail</td>
<td>$24,192</td>
<td>$461</td>
<td>53</td>
</tr>
<tr>
<td>Recreation Centre</td>
<td>$28,400</td>
<td>$263</td>
<td>108</td>
</tr>
<tr>
<td>Secondary School</td>
<td>$36,325</td>
<td>$306</td>
<td>119</td>
</tr>
</tbody>
</table>
The Effectiveness of Adding More Insulation

- Even some “expensive” options look attractive when compared to the cost effectiveness of adding insulation
- The cost to upgrade to thermally broken balconies and parapets for the high-rise MURB with 40% glazing may require **two to three times the cost** of increasing effective wall assembly R-value from R-15.6 to R-20, but
- **Seven times more energy savings**
- Better details AND adding insulation translates to the most energy savings and the best payback period
• Glazing area is major determinant of overall U
• U value of opaque spandrel closer to “glazing” values than “wall” values.
• The heat loss through transition elements such as deflection headers is large and usually not included in manufacturer's data
• Improvements can be made and some manufacturers are starting to make them
How to Improve?

Better Deflection Header?

Vision
Opaque
U-0.21, R-4.7
U-0.21, R-4.8

U-0.21, R-4.7
U-0.14, R-7.2
How to Improve?

Better Deflection Header?

Vision
Opaque
U-0.21, R-4.7
U-0.21, R-4.8

U-0.21, R-4.7
U-0.14, R-7.2
Interior Insulated Concrete Buildings are a Challenge

- Insulation interrupted by slabs and shear walls
- Attachment of windows cold concrete problematic
New and Innovative Technologies

- Cladding attachments
- Structural thermal breaks
- Vacuum insulated panels (VIP) in insulated glazed units for glazing spandrel sections
Structural Thermal Breaks

Balcony connection (image courtesy of Lenton)

Structural thermal break (image courtesy of Fabreeka)

Structural thermal break (image courtesy of Schock)

Thermal break (image courtesy of Halfen)
Readily Available Low Conductivity Structural Materials

PU structural thermal break (image courtesy of General Plastics)

PVC Structural thermal break (image courtesy of Armatherm)

Wood – courtesy of the forest 😊
At Grade Solutions for Structural Thermal Breaks

Aerated Concrete (courtesy of Aercon)

Foam Glass (courtesy of Perinsul)

EPS Concrete (courtesy of Bremat)

Foam Glass (courtesy of Perinsul)
Proprietary Systems with Constant Spacing

- 4”, R-16.8 Exterior Insulation
- Clips/sub-girts at 24” o.c.
Thermal vs. Structural Performance

- Lightweight cladding (5 psf)
- 40 psf Wind
- 18 gauge steel studs
- 4”, R-16.8 Exterior Insulation
The Role of Energy Codes and Standards

- Requiring that thermal bridging at interface details be considered will be the catalyst for market transformation
- Move past the idea that the only thing a designer or authority having jurisdiction needs to check is how much insulation is provided
- The guide can be leverage to help lead the way to constructive changes
• Industry needs a level playing field
• Designers need options
• Incentivize effective solutions
• Changes to code are on the way
Next Steps

• Improve the ability to enforce the code and level the playing field by adding clarity
• Adopt requirements that make sense for our climate and construction practice
• Replace “exceptions” based on wall areas with metrics that represent heat flow like linear transmittance or remove all exceptions
• Create incentives and reward improved details when practical
• Encourage good practice and a holistic design approach
• Use this guide to help policy and authorities implement programs that are more enforceable
mlawton@morrisonhershfield.com