Thermal Bridging:
Small Details with a Large Impact

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ABTG / ARES Consulting
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Foam sheathing research reports, code compliance documents, educational programs and best practices can be found at www.continuousinsulation.org.
Outline

- Types of Thermal Bridges & Implications
- Design and Mitigation Concepts
- Examples of Thermal Bridge Mitigation Strategies
- Calculation Methods and Design Data
- Design Example
- Status of ASHRAE 90.1 Thermal Bridging Work
- Conclusions
- Bibliography (design resources)
What is a thermal bridge?

A thermal bridge is not a burning bridge, although both have something to do with heat transfer.

Source: Steve Dadds; as published in azfamily.com by 3TV/CBS 5, posted Aug. 17, 2015.
What do codes require?

- Framing thermal bridges (studs, tracks, headers, etc.) are accounted for in the prescriptive R-values and U-factor calculations for individual assemblies (walls, roofs, floors, etc.)

- Thermal bridges that occur at intersection of assemblies and components have not commonly been accounted for.
  - ASHRAE 90.1 Performance path has required them to be considered as “uninsulated assemblies”, but this is inaccurate and often not enforced.
  - Prescriptive R-value path (and baseline for the performance path) was built on the assumption of no unaccounted thermal bridges.
What will newer codes require?

- Changes to the 2021 IECC “above-grade wall” definition will require that thermal bridges at assembly and component intersections be addressed in the U-factor of the wall.
  - Some consider this as a clarification of what the code has always required, but has not been consistently enforced
  - Some consider this as a new requirement (relative to accepted practice)

- Changes under review for ASHRAE 90.1 will address these assembly intersection thermal bridges in the prescriptive and performance path; also Appendix A for alternate solutions.
  - Currently preparing a 3rd public review draft
  - Focus mainly on “big” thermal bridges
  - Climate Zones 1-3 exempted
  - Several allowances not requiring 100% mitigation
What are the implications of unaccounted thermal bridges?

- Unaccounted thermal bridges can result in significantly over-estimated building performance
- Inaccurate heating and cooling loads for HVAC equipment sizing
- Moisture problems (condensation, corrosion, mold, rot).
- Diminishes the effective R-value of insulation materials (devalues insulation to extent bridged)

Figure 4.7: Additional building energy use based on thermal performance of the building wall assembly for varying amounts of nominal exterior insulation for a mid-rise MURB in Edmonton (overall assembly thermal resistance in ft²·°F·h/Btu also given)

Source: Morrison Hershfield Ltd
Types of Thermal Bridges

- Clear-field thermal bridge
- Linear thermal bridge
- Point thermal bridge
Clear-Field Thermal Bridge

- Clear-Field Thermal Bridge
  - Thermal pathways inherent to a building assembly and its surface area
  - Generally accounted for in U-factor calculations, R-value prescriptions, and assembly thermal test methods for energy code compliance
  - Examples: Wood and steel studs and plates (framing), webs of concrete masonry units, etc.
  - Impact: For example, cavity insulation in steel framing is only ~35-50% effective
    - Wall with R-21 cavity insulation has effective R-7.4 to R-9.0 for 16”oc and 24”oc stud

- Design Tool: **Steel Wall Calculator**
  - Performs U-factor and water vapor control design checks for coordinated energy code and building code compliance
Linear Thermal Bridge

- **Linear Thermal Bridge:**
  - Additional heat flow caused by details that can be defined by a length along the building surface.
    - Units for “Psi-factor” (Ψ) – linear thermal transmittance:
      - [IP] Btu / hr-ft-oF
      - [SI] W / m-K
  - Usually associated with the intersection of different assemblies and components.
  - Generally not accounted for in the clear-field U-factors used for purposes of “compliance” with 90.1 or IECC:
    - Exceptions:
      1) F-factors for insulation of slab-on-grade foundation edges
      2) Requirement to model “uninsulated assemblies” in performance/simulation path.

Source: Morrison Hershfield LTD / ASHRAE RP 1365
Linear Thermal Bridge

- **Examples:** Slab floor edges, balconies, shelf-angles, corners, parapets, window-wall interface, int/ext wall interface, floor-wall interface, foundation-slab interface, furring penetrating through insulation, columns or beams in the plane of an assembly, etc.
- **Impact:** Depending on quantity and detailing used, these heat flows can account for 20-70% of total opaque envelope heat flow!

Source: USACE report
• **Point Thermal Bridge:**
  - Heat flow caused by a thermal bridge that occurs at single element or discrete “point”
    - Units for “Chi-factor” \( (\chi) \) – point thermal transmittance:
      - [IP] Btu/hr-oF
      - [SI] W/K
    - Generally not accounted for in U.S. energy codes and standards
  - **Examples:** Pipes, beams, and column penetrations through building envelope
    - Fasteners, brackets, ties, etc. also can be treated as point thermal bridges, but are best addressed as part of the assembly U-factor calculation if distributed uniformly and repetitively over area of assembly
  - **Impact:** Assembly U-factor increased from 1% to 40% depending on amount of insulation penetrated, size and spacing of penetrations, type of structural substrate, penetrating material conductivity, 3-D geometry, etc.
Design Concepts for Clear-Field Thermal Bridges

- Clear-field thermal bridges generally are required to be accounted for in U-factor calculations or tests for assemblies:
  - Refer to ASHRAE 90.1 Appendix A and Handbook of Fundamentals
    - Light-frame construction and metal building systems account for thermal bridging caused by framing members within the assemblies
  - Some U-factor calculation methods are empirical and include some amount of fastener point thermal bridges; some may include brick ties; some don’t address impact of fasteners at all (cladding, interior finish, exterior sheathing, etc.).
  - Can model or test assemblies, but all relevant thermal bridges in the “as-constructed” assembly must be included
Mitigation Concepts for Clear-Field Thermal Bridges

- Some ways to mitigate clear field thermal bridges include:
  - Reduce “framing factor” where structurally feasible (wider frame spacing, double stud framing, etc.)
  - Use low conductivity structural materials
  - Apply continuous insulation over structure/framing members (minimize discontinuity at floor/wall/roof intersections)
  - Mount furring over (not through) continuous insulation layer
  - Use low conductivity fasteners or devices to attach cladding, furring, etc. to framing (e.g., stainless steel, carbon fiber, etc.)

Before

R-13 batts in cavity between studs

After

R13 + ½” rigid foam continuous insulation over studs

Source: Dryvit/Dow
Mitigation Concepts for Point Thermal Bridges

- Some ways to mitigate point thermal bridges include:
  - Minimize penetrations of high thermal conductivity materials through the building envelope.
  - Encapsulate the penetrating element with insulation for at least 2 feet inward or outward from the envelope.
  - Use lower conductivity materials
    - Stainless steel
      - 3x lower thermal conductivity than carbon steel
      - 5x lower thermal conductivity than aluminum
      - More durable (benefit for cladding attachments)
    - Various proprietary thermal break materials and devices
Mitigation Concepts for Linear Thermal Bridges

- Some ways to mitigate linear thermal bridges include:
  - Convert a linear thermal bridge to a series of point thermal bridges to disrupt and minimize heat flow pathway
  - Examples:
    - Offset brick shelf angle and continuous insulation
    - Offset furring (on surface of continuous insulation and fastened through at points)
    - Thermally broken or self-supported balconies
    - Fenestration interface (alignment with insulation and insulation of exposed rough opening)
    - Floor edges (continuous insulation)
    - Foundation edges (continuous insulation) – F-factors don’t account for all the options to maximize placement and value of insulation to minimize slab edge heat loss
    - Various proprietary structural thermal break devices
Examples of Mitigated Linear Thermal Bridges
(Balconies)

Suspended and separately supported balconies with shear tab or offset shelf-angle point connection to building

Photos courtesy of John Hogan
More Examples of Mitigated Linear Thermal Bridges (non-exhaustive “commodity” details)

Example Details from BSI-081: Zeroing In (J. Lstiburek, Building Science Corp) as used on NIST NZERTF Project

OFFSET SHELF ANGLE (AISC/SEI article)

INSULATED WINDOW ROUGH OPENING DETAIL (USACE report)

INSULATED PARAPET DETAILS (Payette/AIA report)
Examples of Proprietary Thermal Bridging Devices
(non-exhaustive “google” search)

Cantilevered Balcony Structural Thermal Break
Source: Google search

Structural thermal block for steel beam projections through building envelope
Source: Google search

Low thermal conductivity furring/cladding/ledger supports
Sources: Payette/AIA report and product info from Google search
Calculations to Account for Point & Linear Thermal Bridges

\[
Q = \left[ \sum (U_i \cdot A_i) + \sum (\psi_j \cdot L_j) + \sum (\chi_k \cdot n_k) \right] \times \Delta T
\]

where:

- \( Q \) = heat transfer through envelope by conduction (static)
- \( U_i \) = U-factor for assembly type \( i \)
- \( A_i \) = Total surface area of assembly type \( i \)
- \( \psi_j \) = Psi-factor for linear thermal bridge type \( j \)
- \( L_j \) = Total length of linear thermal bridge type \( j \)
- \( \chi_k \) = Chi-factor for point thermal bridge type \( k \)
- \( n_k \) = number of point thermal bridges of type \( k \)

\[
U_{adj} = \frac{\Sigma (\psi_j \cdot L_j) + \Sigma (\chi_k \cdot n_k)}{A_{Total}} + U_o
\]

where:

- \( U_{adj} \) = adjusted U-factor for use in “tricking” simulation model to account for thermal bridges that may be associated with but not “in” the assembly.
- \( U_o \) = clear-field U-factor for the assembly being adjusted

Source: BC Hydro BETB Guide / Morrison Hershfield LTD
### Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Description and Examples</th>
<th>Linear Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FLOOR AND BALCONY SLABS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Efficient</strong></td>
<td>Fully insulated with only small conductive bypasses&lt;br&gt;Examples: exterior insulated wall and floor slab.</td>
<td>0.12 0.2</td>
</tr>
<tr>
<td><strong>Improved</strong></td>
<td>Thermally broken and intermittent structural connections&lt;br&gt;Examples: structural thermal breaks, stand-off shelf angles.</td>
<td>0.20 0.35</td>
</tr>
<tr>
<td><strong>Regular</strong></td>
<td>Under-insulated and continuous structural connections&lt;br&gt;Examples: partial insulated floor (i.e. firestop), shelf angles attached directly to the floor slab.</td>
<td>0.29 0.5</td>
</tr>
<tr>
<td><strong>Poor</strong></td>
<td>Un-insulated and major conductive bypasses&lt;br&gt;Examples: un-insulated balconies and exposed floor slabs.</td>
<td>0.58 1.0</td>
</tr>
</tbody>
</table>

Source: BC Hydro BETB Guide / Morrison Hershfield LTD
## Example Design Data
(Psi-factors for fenestration-wall interface)

### Table 1.4: Performance Categories and Default Transmittances for Glazing Transitions

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Description and Examples</th>
<th>Linear Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficient</strong></td>
<td>Well aligned glazing without conductive bypasses. Examples: wall insulation is aligned with the glazing thermal break. Flashing does not bypass the thermal break.</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Regular</strong></td>
<td>Misaligned glazing and minor conductive bypasses. Examples: wall insulation is not continuous to thermal break and framing bypasses the thermal insulation at glazing interface.</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Poor</strong></td>
<td>Un-insulated and conductive bypasses. Examples: metal closures connected to structural framing. Un-insulated concrete opening (wall insulation ends at edge of opening).</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Source: BC Hydro BETB Guide / Morrison Hershfield LTD
Example Design Data
(Psi-factors for parapet roof-wall intersection)

### Table 1.5: Performance Categories and Default Transmittances for Parapets

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Description and Examples</th>
<th>Linear Transmittance</th>
</tr>
</thead>
</table>
| **Efficient**        | Roof and Wall Insulation Meet at the Roof Deck
Examples: structural thermal break at roof deck, wood-frame parapet. | 0.12 | 0.2 |
| **Improved**         | Fully Insulated Parapet
Examples: insulation wraps around the parapet to the same insulation level as the roof and wall. | 0.17 | 0.3 |
| **Regular**          | Under-insulated Parapets
Examples: concrete parapet is partially insulated (less than roof insulation), insulated steel framed parapet, concrete block parapet. | 0.26 | 0.45 |
| **Poor**             | Un-insulated and major conductive bypasses
Examples: exposed parapet and roof deck. | 0.46 | 0.8 |

Source: BC Hydro BETB Guide / Morrison Hershfield LTD
Example Design Data
(Chi-factors for metal/fastener penetrations)

### TABLE 2
Representative Point Thermal Bridge Thermal Transmittance Values
(Chi-Factors, \(\text{Btu/in}^2\text{F per in}^2\) of fastener area)
for Various Assembly Types and Metal (Carbon Steel) Penetration Conditions
(based on rough approximations from data in Table 1)^1

<table>
<thead>
<tr>
<th>R-value of Insulation component layer penetrated by metal element</th>
<th>Steel Framing</th>
<th>Wood Framing</th>
<th>Concrete/Masonry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roof (Metal Deck)</td>
<td>Wall (Steel Studs)</td>
<td>Roof (WSP Deck)</td>
</tr>
<tr>
<td>Carbon steel fastener/connector through above-deck insulation to steel deck</td>
<td>0.03^2</td>
<td>0.04 (Mayer et al., 2014)</td>
<td>0.31^2</td>
</tr>
<tr>
<td>R-0.5 (e.g., non-insulating sheathing)</td>
<td>0.13^2</td>
<td>0.2^2</td>
<td>0.1 (Burch et al., 1987)</td>
</tr>
<tr>
<td>R-5cl</td>
<td>0.2 (Viealnd, 2006; Burch et al., 1987; ISO 9046 Eq. D.5)</td>
<td>0.3^2 (Mayer et al., 2014; Posey and Dallalbash, 2005, and unpublished data)</td>
<td>0.15 (Burch et al., 1987; ISO 9046 Eq. D.5)</td>
</tr>
<tr>
<td>R-10cl</td>
<td>0.05 (Viealnd, 2006; ISO 9046 Eq. D.5)</td>
<td>0.05^2</td>
<td>0.05^2</td>
</tr>
</tbody>
</table>

Table Notes:
1. Interpolation is permissible between R-values of penetrated insulation in the left column.
2. Values are based at least in part on data trends in adjacent cell(s) or column of table and are provided only as a means to facilitate completeness of the table and interpolation. Additional research and confirmation is recommended.
3. Based on other modeled data for energy efficient brick ties (e.g., wire ties with hooked connections that disrupt the heat flow path), the normalized chi-factor may be as low as ~1.5 \(\text{Btu/in}^2\text{F per in}^2\) of tie cross-section area penetrating insulation (pers. comm. Patrick Roppel, Morrison-Hemphill, Jan. 15, 2016).

Chi-factors for Carbon-Steel Penetration through Exterior Insulation

Source: ABTG RR No. 1510-03
# Clear-field U-factor Analysis – CFS steel frame wall with and without ci

## 2015 IECC Climate Zones & Insulation (C402.1.4.1 Calculation Method)

<table>
<thead>
<tr>
<th>Wall Component</th>
<th>Zone 1, 2</th>
<th>Zone 2-8</th>
<th>Zone 7res</th>
<th>Zone 8res</th>
<th>n/a</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4”C-stud</td>
<td>4” C-stud</td>
<td>6” C-stud</td>
<td>4” C-stud</td>
<td>4” C-stud</td>
<td>6” C-stud</td>
</tr>
<tr>
<td>Outside air film</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Siding</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>Continuous insulation</td>
<td>5</td>
<td>10</td>
<td>8.5</td>
<td>15.6</td>
<td>17.5</td>
<td>0</td>
</tr>
<tr>
<td>Gypsum Sheathing 1/2”</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>subtotal exterior R-value:</td>
<td>6.07</td>
<td>11.07</td>
<td>9.57</td>
<td>16.67</td>
<td>18.57</td>
<td>1.07</td>
</tr>
<tr>
<td>Cavity Insulation</td>
<td>13</td>
<td>13</td>
<td>19</td>
<td>13</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Cavity Correction Factor</td>
<td>0.46</td>
<td>0.46</td>
<td>0.37</td>
<td>0.46</td>
<td>0.46</td>
<td>0.37</td>
</tr>
<tr>
<td>Eff. Cavity insulation</td>
<td>5.98</td>
<td>5.98</td>
<td>7.03</td>
<td>5.98</td>
<td>5.98</td>
<td>7.03</td>
</tr>
<tr>
<td>1/2 drywall (int. R-value)</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Inside air film</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Nom. U-Factor (no fasteners)</td>
<td>0.075</td>
<td>0.054</td>
<td>0.056</td>
<td>0.042</td>
<td>0.039</td>
<td>0.106</td>
</tr>
<tr>
<td>Effective R (no fasteners)</td>
<td>13.4</td>
<td>18.4</td>
<td>17.9</td>
<td>24.0</td>
<td>25.9</td>
<td>9.4</td>
</tr>
</tbody>
</table>

## U-factor increase due to fastener heat loss (delta-U = Chi x FAR x 144in²/ft²):

| Siding fasteners               | 0.00547  | 0.00848  | 0.00819  | 0.00719  | 0.00675  | 0.00158  | 0.00454  |
| CI fasteners                   | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  |
| Ext Gyp fasteners              | 0.00060  | 0.00044  | 0.00051  | 0.00033  | 0.00031  | 0.00097  | 0.00070  |
| Drywall fasteners              | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  | 0.00000  |
| Total add to U:                | 0.00607  | 0.00892  | 0.00870  | 0.00752  | 0.00706  | 0.00255  | 0.00523  |
| U-factor (with fasteners)      | 0.0810   | 0.0634   | 0.0646   | 0.0493   | 0.0457   | 0.1089   | 0.0792   |
| Effective R (with fasteners)   | 12.35    | 15.77    | 15.49    | 20.29    | 21.86    | 9.18     | 12.63    |
| Factor increase in nom. U      | 1.08     | 1.16     | 1.16     | 1.18     | 1.18     | 1.02     | 1.07     |

---

**Fastener area ratio for penetrations through interior and exterior surface layers:**

\[ \text{FAR} = \frac{\text{fastener cross-section area (in}^2\text{)} \times 100\%}{\text{wall area (in}^2\text{)}} \]

- **0.020%**: Siding fastener area ratio (see below)
- **0.0000%**: Continuous insulation fastener ratio (see note below)
- **0.018%**: Gypsum exterior sheathing fastener ratio (see note below)

Notes on fasteners as addressed in C402.1.4.1 calculation method:

1. CI fasteners are implicit to the derivation of cavity correction factors for steel framing
2. Exterior gypsum fasteners may only be partially addressed in the cavity correction factors
3. Interior gypsum fasteners are accounted for and implicitly to the cavity correction factors

**Typical steel frame wall framing surface layer connections:**

- **gypsum int. = 12"x16" #6 screws, 0.016in² = 0.008%**
- **Gypsum ext. = 62 #8 screws per 32sqft, 0.021in² = 0.028%**
- **CI board = 42 #8 screws per 32sqft, 0.0.021in² = 0.019%**
- **6" Lap Siding = 1 screw, 0.016in², per 80in² = 0.02%**
- **Brick Ties = 2" x 0.033" tie at 16"x24", 2.67ft² = 0.017%**

Source: ABTG RR No. 1510-03
Design Example
(3-story office building)

Structure: Steel Frame Walls with Concrete Slab Floors

All cases include metal stud clear field thermal bridges within assembly

CASE 1: No Thermal Bridges (ideal) w/ R13 cavity insulation only

<table>
<thead>
<tr>
<th>Transmittance Type</th>
<th>Transmittance Description</th>
<th>Area, Length or Amount Takeoff</th>
<th>Units</th>
<th>Transmittance Value</th>
<th>Units</th>
<th>Heat Flow (BTU/hr°F)</th>
<th>%Total Heat Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Field</td>
<td>Opaque Wall Area (R13 cavity insulation only)</td>
<td>14267.00 ft²</td>
<td></td>
<td>0.124</td>
<td></td>
<td>1769.1</td>
<td>100%</td>
</tr>
</tbody>
</table>

CASE 2: No thermal bridges (ideal) w/ R13+10ci insulation per 90.1

<table>
<thead>
<tr>
<th>Transmittance Type</th>
<th>Transmittance Description</th>
<th>Area, Length or Amount Takeoff</th>
<th>Units</th>
<th>Transmittance Value</th>
<th>Units</th>
<th>Heat Flow (BTU/hr°F)</th>
<th>%Total Heat Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Field</td>
<td>Opaque Wall Area (R13+10 per ASHRAE 90.1)</td>
<td>14267.00 ft²</td>
<td></td>
<td>0.055</td>
<td></td>
<td>784.7</td>
<td>100%</td>
</tr>
</tbody>
</table>

Overall Opaque Wall Thermal Performance

<table>
<thead>
<tr>
<th></th>
<th>Opaque U-Value (BTU/hr ft²°F)</th>
<th>Effective R-Value (hr ft²°F/BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1</td>
<td>0.124</td>
<td>8.1</td>
</tr>
<tr>
<td>CASE 2</td>
<td>0.055</td>
<td>18.2</td>
</tr>
</tbody>
</table>

Case 2 mitigates the clear-field framing thermal bridges within the assembly.
Design Example  
(3-story office building)

CASE 3: R13+10 with Poor Thermal Bridging Details Included (64% of opaque wall heat flow)

<table>
<thead>
<tr>
<th>Transmittance Description</th>
<th>Area, Length or Amount Takeoff</th>
<th>Units</th>
<th>Transmittance Value</th>
<th>Units</th>
<th>Source Reference</th>
<th>Heat Flow (BTU/hr ft² °F)</th>
<th>%Total Heat Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque Wall Area</td>
<td>14267.00</td>
<td>ft²</td>
<td>0.055</td>
<td>BTU/hr ft² °F</td>
<td>BCNA65</td>
<td>784.7</td>
<td>37%</td>
</tr>
<tr>
<td>Opaque Roof – Opaque Wall Intersection (Parapet)</td>
<td>546.00</td>
<td>ft</td>
<td>0.400</td>
<td>BTU/hr ft² °F</td>
<td>2.23</td>
<td>218.4</td>
<td>10%</td>
</tr>
<tr>
<td>Opaque Wall – Above-grade Floor Intersection</td>
<td>1638.00</td>
<td>ft</td>
<td>0.500</td>
<td>BTU/hr ft² °F</td>
<td>5.25</td>
<td>819.0</td>
<td>38%</td>
</tr>
<tr>
<td>Opaque Wall – Interior Wall Intersection</td>
<td>166.00</td>
<td>ft</td>
<td>0.134</td>
<td>BTU/hr ft² °F</td>
<td>0.0</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td>Opaque Wall - Balcony Intersection</td>
<td>197.00</td>
<td>ft</td>
<td>0.600</td>
<td>BTU/hr ft² °F</td>
<td>5.25</td>
<td>118.2</td>
<td>6%</td>
</tr>
<tr>
<td>Opaque Wall - Horizontal Fenestration Intersection</td>
<td>1092.00</td>
<td>ft</td>
<td>0.190</td>
<td>BTU/hr ft² °F</td>
<td>5.31</td>
<td>207.5</td>
<td>10%</td>
</tr>
</tbody>
</table>

Overall Opaque Wall Thermal Performance*:
- Opaque U-Value (BTU/hr ft² °F): 0.151
- Effective R-Value (hr ft² °F/BTU): 6.6

* U-factor and effective R-value of opaque wall area is adjusted to include effect of various unmitigated linear thermal bridges at wall-to-floor, -fenestration, and -roof assembly intersections
Design Example
(3-story office building)

CASE 4: R13+10 with Efficient/Mitigated Thermal Bridging Details (now 25% of wall heat flow)

<table>
<thead>
<tr>
<th>Transmittance Description</th>
<th>Area, Length or Amount Takeoff</th>
<th>Units</th>
<th>Transmittance Value</th>
<th>Units</th>
<th>Source Reference</th>
<th>Heat Flow (BTU/hr*ft^2)</th>
<th>% Total Heat Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque Wall Area</td>
<td>14267.00 ft^2</td>
<td></td>
<td>0.055</td>
<td>BTU/ hr*ft^2 °F</td>
<td>BC Hydro</td>
<td>784.7</td>
<td>75%</td>
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<tr>
<td>Opaque Roof – Opaque Wall Intersection</td>
<td>546.00 ft</td>
<td></td>
<td>0.150</td>
<td>BTU/ hr*ft °F</td>
<td>55.7</td>
<td>81.9</td>
<td>6%</td>
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<tr>
<td>Opaque Wall – Above-grade Floor Intersection</td>
<td>1639.00 ft</td>
<td></td>
<td>0.020</td>
<td>BTU/ hr*ft °F</td>
<td>5.33</td>
<td>32.8</td>
<td>3%</td>
</tr>
<tr>
<td>Opaque Wall – Interior Wall Intersection</td>
<td>156.00 ft</td>
<td></td>
<td>0.134</td>
<td>BTU/ hr*ft °F</td>
<td>55.1</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td>Opaque Wall - Balcony Intersection</td>
<td>197.00 ft</td>
<td></td>
<td>0.117</td>
<td>BTU/ hr*ft °F</td>
<td>52.73</td>
<td>23.0</td>
<td>2%</td>
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<tr>
<td>Opaque Wall - Horizontal Fenestration Intersection</td>
<td>1092.00 ft</td>
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<td>0.110</td>
<td>BTU/ hr*ft °F</td>
<td>53.8</td>
<td>120.1</td>
<td>12%</td>
</tr>
</tbody>
</table>

**Overall Opaque Wall Thermal Performance**

- **Opaque U-Value (BTU/hr*ft^2 °F)**: 0.073
- **Effective R-Value (hr*ft^2 °F/BTU)**: 13.7

* U-factor and effective R-value of opaque wall area is adjusted to include effect of various mitigated linear thermal bridges at wall-to-floor, -fenestration, and -roof assembly intersections
Conclusions

- Thermal bridging has generally been ignored and unregulated, except as they occur due to framing members within assemblies.
- Unaccounted thermal bridging can account for 20-70% of heat flow through the building’s opaque envelope.
- Reasonable efforts to use improved details to mitigate point and linear thermal bridges can significantly improve building envelope performance.
- For buildings with significant types or quantities of thermal bridges, it is beneficial to mitigate thermal bridges, especially when considering increased insulation amounts above minimum code levels.
- Several sources of data and design guidance are available to support appropriate consideration and mitigation of thermal bridges (see Bibliography).
- Energy codes and standards are changing to better address thermal bridging effects.
Bibliography

Questions?

Jay Crandell

www.aresconsulting.biz

Please submit any questions through the Continuous Insulation website at continuousinsulation.org/contact.