The Concept of Linear and Point Transmittance and its Value in Dealing with Thermal Bridges in Building Enclosures

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Presentation Outline

1. How do we deal with thermal bridging?
2. The Conceptual Leap
3. How can we use this now?
4. How might we use this in the future?
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Thermal Bridging

What is a Thermal Bridge?

- Highly conductive material that bypasses insulation layer
- Areas of high heat transfer
- Can greatly affect the thermal performance of assemblies
How does heat flow through an enclosure assembly?

vs.

How to comply with energy standards like ASHRAE 90.1
Largely silent on thermal bridging outside of assemblies

Generally not being accounted for

Provision to account for uninsulated wall assemblies in Appendix G (i.e. LEED requirement)

5% exemption in Energy Cost Budget (for simplicity)
### TABLE A3.3 Assembly U-Factors for Steel-Frame Walls

<table>
<thead>
<tr>
<th>Framing Type and Spacing Width (Actual Depth)</th>
<th>Cavity Insulation R-Value: Rated (Effective Installed [see Table A9.2B])</th>
<th>Overall U-Factor for Entire Base Wall Assembly</th>
<th>Overall U-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (0.0)</td>
<td></td>
<td>0.352</td>
<td>R-1.00  R-2.00  R-3.00  R-4.00  R-5.00  R-6.00  R-7.00  R-8.00</td>
</tr>
<tr>
<td>3.5 in. depth</td>
<td></td>
<td>0.132</td>
<td>0.117  0.105  0.095  0.087  0.080  0.074  0.069  0.064</td>
</tr>
<tr>
<td>R-11 (5.5)</td>
<td></td>
<td>0.132</td>
<td>0.117  0.105  0.095  0.087  0.080  0.074  0.069  0.064</td>
</tr>
<tr>
<td>R-13 (6.0)</td>
<td></td>
<td>0.124</td>
<td>0.100  0.091  0.083  0.077  0.071  0.066  0.065  0.062</td>
</tr>
<tr>
<td>R-15 (6.4)</td>
<td></td>
<td>0.118</td>
<td>0.106  0.096  0.087  0.080  0.074  0.069  0.066  0.062</td>
</tr>
</tbody>
</table>

- **Steel Framing at 16 in. on center**:
  - None (0.0) Overall U-Factor = 0.352
  - 3.5 in. depth Overall U-Factor = 0.132
  - R-11 (5.5) Overall U-Factor = 0.124
  - R-13 (6.0) Overall U-Factor = 0.118
  - R-15 (6.4) Overall U-Factor = 0.106

For Rated R-Value of Continuous Insulation:
- R-1.00 = 0.260
- R-2.00 = 0.207
- R-3.00 = 0.171
- R-4.00 = 0.146
- R-5.00 = 0.128
- R-6.00 = 0.113
- R-7.00 = 0.102
- R-8.00 = 0.092

When the cavity insulation is R-11 (5.5), the overall U-Factor is equal to 0.124, which is equal to R-8. When combined with R-8, the overall U-Factor becomes R-16, which is equal to R-8 + R-8.
Thermal Bridging

How is Thermal Bridging Typically Evaluated?

- Computer Modeling
- Hand Calculations
- Lab Measurement
We Live in a 3D World!
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
Area-Weighted Average

Determining Areas of Influence

$L_{\text{exterior}}$

$L_{\text{interior}}$

$L_{\text{par}}$

$L_{\text{ro}}$
Is there a more straightforward way to characterize thermal bridges in details?
Presentation Outline

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The Conceptual Leap

Types of Transmittances

Clear Field

Linear

Point

$U_o$

$\Psi$

$\chi$

psi

chi
Calculating Transmittances

$Q = Q_o - Q_{\text{slab}}$

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.

\[ \Psi = \frac{Q_{slab}}{L} \]
Heat Loss Calculations

Total Heat loss

= due to clear field + Heat loss due to anomalies

\[
\frac{Q}{\Delta T} = (U_o \cdot A_{Total}) + \sum (\Psi \cdot L) + \sum (\chi \cdot n)
\]
Heat Loss Calculations

\[ U = \frac{Q}{\Delta T \cdot A_{Total}} \]

or

\[ U = \frac{\sum (\Psi \cdot L) + \sum (\chi \cdot n)}{A_{Total}} + U_o \]

The assembly U-factor is the clear field U-factor, plus all the linear and point transmittances.
Presentation Outline

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### Base Assembly – Concrete Wall

<table>
<thead>
<tr>
<th>$R_{1D}$</th>
<th>$R_{o}$</th>
<th>$U_{o}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft² hr °F / Btu (m² K / W)</td>
<td>ft² hr °F / Btu (m² K / W)</td>
<td>Btu/ft² hr °F (W/m² K)</td>
</tr>
<tr>
<td>R-13.09 (2.30)</td>
<td>R-12.64 (2.22)</td>
<td>0.079 (0.45)</td>
</tr>
</tbody>
</table>

### Panel Edge Transmittance

<table>
<thead>
<tr>
<th>$R_{e}$</th>
<th>$U_{e}$</th>
<th>$\psi_{e}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft² hr °F / Btu (m² K / W)</td>
<td>Btu/ft² hr °F (W/m² K)</td>
<td>Btu/ft hr °F (W/m K)</td>
</tr>
<tr>
<td>R-11.67(2.05)</td>
<td>0.086 (0.49)</td>
<td>0.013 (0.023)</td>
</tr>
</tbody>
</table>

### Slab Transmittance

<table>
<thead>
<tr>
<th>$R_{p}$</th>
<th>$U_{p}$</th>
<th>$\psi_{p}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft² hr °F / Btu (m² K / W)</td>
<td>Btu/ft² hr °F (W/m² K)</td>
<td>Btu/ft hr °F (W/m K)</td>
</tr>
<tr>
<td>R-8.75 (1.54)</td>
<td>0.114 (0.65)</td>
<td>0.118 (0.205)</td>
</tr>
</tbody>
</table>

### Temperature Indices

<table>
<thead>
<tr>
<th>$T_{11}$</th>
<th>$T_{12}$</th>
<th>$T_{13}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.734</td>
<td>0.820</td>
<td>0.915</td>
</tr>
</tbody>
</table>

- **$T_{11}$**: Min T on interior concrete wall, at slab and panel joint
- **$T_{12}$**: Max T on concrete wall, at slot anchor
- **$T_{13}$**: Min T in interior surface, at floor/gypsum intersection and anchor
Evaluating Cladding Attachments

Comparing to ASHRAE 90.1-2007 Requirements

- Vertical Z-Girts
- Horizontal Z-Girts
- Mixed Z-Girts
- Intermittent Z-Girts
Glazing Spandrel Areas

Curtain Wall Comparison

Spray Foam
Glazing Spandrel Areas

Back Pan Insulation

Spandrel Section R Value

Detail 22 (Air in Stud Cavity)  Detail 23 (Spray Foam in Stud Cavity)
So what about strong thermal Bridges that are not distributed by area?

ASHRAE allows lumping ones of <5% of wall area into adjacent area (for ease of calculation and compliance assessment)
Concrete Balcony Slab Edge

<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>0.81</td>
<td>0.47</td>
</tr>
</tbody>
</table>

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)
Concrete Walls
Concrete Walls

<table>
<thead>
<tr>
<th>Party Wall with no wall insulation</th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ψ</td>
<td>0.67</td>
<td>0.39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Party Wall with R-5 wall insulation</th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ψ</td>
<td>0.45</td>
<td>0.26</td>
</tr>
</tbody>
</table>
Slab Edges – Brick Veneer

<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>0.59</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Slab Edges – Brick Veneer

<table>
<thead>
<tr>
<th>Shelf Angle</th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Psi$</td>
<td>0.47</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Slab Edges - Brick Veneer

<table>
<thead>
<tr>
<th>Spaced Shelf Angle</th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Psi )</td>
<td>0.31</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Slab Edges – Exterior Insulated

<table>
<thead>
<tr>
<th>R-15 Insulated Slab Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Psi )</td>
</tr>
<tr>
<td>0.16</td>
</tr>
</tbody>
</table>
Balcony slab w Isokorb $\Psi = 0.20 \text{ W/m-K or 0.12 BTU/hr\cdot ft^{o}F}$
Exterior Insulated Steel Stud Assemblies

<table>
<thead>
<tr>
<th>R-15 Insulated Parapet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SI</strong> (W/m·K)</td>
</tr>
<tr>
<td>Ψ</td>
</tr>
</tbody>
</table>
Exterior Insulated Steel Stud Assemblies

<table>
<thead>
<tr>
<th>R-15 Insulated Post</th>
<th>SI (W/m·K)</th>
<th>IP (BTU/hr·ft·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ψ</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R-15 Insulated HSS Beam</th>
<th>SI (W/K)</th>
<th>IP (BTU/hr·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>χ</td>
<td>0.08</td>
<td>0.16</td>
</tr>
</tbody>
</table>
### Accounting for Details

#### Table 3.1. Linear Transmittance Ranges

<table>
<thead>
<tr>
<th>Transmittance Range</th>
<th>Slabs</th>
<th>Parapets</th>
<th>Corners</th>
<th>Window Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient (Fully insulated, thermally broken systems)</td>
<td>&lt; 0.15</td>
<td>&lt; 0.20</td>
<td>&lt; 0.03</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.25)</td>
<td>(0.35)</td>
<td>(0.05)</td>
<td>(&lt; 0.10)</td>
</tr>
<tr>
<td>Average (Partially insulated systems, small conductive bypasses)</td>
<td>0.15-0.30</td>
<td>0.20-0.40</td>
<td>0.03-0.15</td>
<td>0.05-0.10</td>
</tr>
<tr>
<td></td>
<td>(0.25-0.50)</td>
<td>(0.35-0.70)</td>
<td>(0.05-0.25)</td>
<td>(0.10-0.20)</td>
</tr>
<tr>
<td>Poor (Un-insulated systems, large conductive bypasses)</td>
<td>&gt; 0.30</td>
<td>&gt; 0.40</td>
<td>&gt; 0.15</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td></td>
<td>(&gt; 0.50)</td>
<td>(&gt; 0.70)</td>
<td>(&gt; 0.25)</td>
<td>(&gt; 0.20)</td>
</tr>
</tbody>
</table>
Accounting for Details

How much extra heat loss can details add?

- **Standard 90.1-2004 Prescriptive Requirements for Zone 5**
  - Mass Wall, U-0.090 or R-11.4 ci
  - Steel-Framed Wall, U-0.064 or R-13 + R-7.5 ci

Mass wall with R-11 insulation inboard; U-0.074

Steel stud with R-10 exterior insulation and horizontal girts at 24”o.c and R-12 in the stud cavity; U-0.061
Accounting for Details

**Typical Building**

**Mass Concrete Wall**
- Exposed concrete slab
- Un-insulated concrete parapet
- Punched window in concrete opening

**Steel-Framed Wall**
- Exterior insulated structural steel floor intersection
- Insulated steel stud parapet
- Punched window in steel stud opening with perimeter flashing

- 10 floors
- 20% glazing
- Standard details
## Accounting for Details

<table>
<thead>
<tr>
<th>Transmittance Type</th>
<th>Mass Concrete Wall</th>
<th>Exterior Insulated Steel Stud</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat Loss (BTU/hr °F)</td>
<td>% of Total</td>
</tr>
<tr>
<td>Clear Wall</td>
<td>118</td>
<td>52 %</td>
</tr>
<tr>
<td>Slab</td>
<td>92</td>
<td>40%</td>
</tr>
<tr>
<td>Parapet</td>
<td>9</td>
<td>4%</td>
</tr>
<tr>
<td>Window transition</td>
<td>8</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>227</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>
### Accounting for Details

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Mass Concrete Wall</th>
<th>Exterior Insulated Steel Stud</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASHRAE Prescriptive Requirements</td>
<td>Overall Performance</td>
</tr>
<tr>
<td><strong>U</strong> (Btu/hr ft² oF)</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>“Effective” R (hr ft² oF/BTU)</td>
<td>R-11</td>
<td>R-7</td>
</tr>
<tr>
<td>% Difference</td>
<td>44%</td>
<td></td>
</tr>
</tbody>
</table>
Insulated Metal Panels

- **IMP Panel Example** - effectively continuous insulation but...

- Potentially 40% (plus) heat flow attributed to window transition
- Panel assembly of U-0.048 is only U-0.127 (effective R-21 to R-8) when considering thermally inefficient details
- Improved to U-0.065 (R-15) without much difficulty (no continuous metal flashing)
Figure 4.5: Effects of variations of opaque wall thermal resistance on space heating for a mid-rise high efficiency MURB
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)
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1. How do we deal with thermal bridging?
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3. How can we use this now?
4. How might we use this in the future?
Well suited for manufacturers for product development, performance evaluation, and marketing
The Future

• It will likely become increasingly more difficult to ignore thermal bridging at intersections of assemblies
• Move beyond simply adding “more insulation”
• Better able to evaluate condensation resistance to improve building durability and occupant comfort
Different approaches can be employed in standards to fully account for thermal bridging using the same data:

- Performance based
- Prescriptive based
- Solutions based

The method of linear transmittance, as part of the 1365-RP methodology, promises to enable more development and enforcement.
1. It may not matter how much insulation you add if most of the heat loss is through the details.

2. There is an “easy” way to evaluate thermal bridging by harnessing the power of 3D modeling to analyze common detail and provide generalizable results.

3. We can separate the clear field from major thermal bridges and **categorize** the thermal quality of details.

4. There is a way of addressing thermal bridging in energy standards such as ASHRAE 90.1.
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