Determining the Thermal Performance of Your Building Enclosure:
Assessing Thermal Bridges

January 11, 2012
AGENDA

Introduction
Program Overview
Project Examples
Solid portions of the building envelope can affect the building's energy usage in 3 ways, but this presentation focuses on the thermal resistance (R-value) of the assemblies.
Historically, solid monolithic walls served all the functions (structural, thermal, acoustical, etc.) required of the building envelope.
Current walls are now comprised of individual layers that have been optimized for the function that they serve.
However, these layers are all held together with highly conductive materials, most commonly metal.
If you have 1” of XPS insulation you have a U-value of 0.2.
If you add another inch, doubling the amount to 2", your heat flow through the wall is cut in half.
If you add yet another inch of insulation, the heat flow through that wall only decreases by about a third.
And so on . . . as you increase the amount of insulation there are diminishing returns.
If thermal bridges occur through the insulation this increases the heat flow and the U-value of the assembly.
However when there is little insulation, increasing the amount of insulation still significantly decreases the heat flow, so the thermal bridge is not as much of a concern.
As you continue to increase the amount of insulation, it has less and less impact, and the thermal bridges become the dominant source of heat loss.
Current code requirements are for approximately 4” of insulation, and research on thermal bridges indicate the heat flow through the bridges to be about equal or more. To further improve the performance of our facades going forward, we need to address the thermal bridges in our design.
In professional practice there is little knowledge and understand of the impact that thermal bridges have in our design, as can be seen in the varied results of the survey.
THERMAL BRIDGING | SURVEY RESULTS

TOTAL R-Value = -66%

These are a few examples of varying wall assemblies with the same amount of insulation showing the range of impact thermal bridges can have.
THERMAL BRIDGING | SURVEY RESULTS

Stick Clip -2%
Dovetail Anchor -17%
Shelf Angle -34%

TOTAL R-Value = -45%
Even this thermally broken rainscreen system is impacted by thermal bridges.
Eliminating all metal and highly conductive elements from penetrating the insulative layer has the best performance.
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The challenge with understanding thermal bridges is that they are a 3D heat flow problem, but energy modeling software only can account for 1D heat flow.
Heat flow through the envelope is analogous to current flow in an electrical circuit, where each layer of the assemblies provides thermal resistance in series. This is how energy models account for heat lost and gained through the building envelope.
When there is an element bridging the insulation, a parallel path of heat flow develops, and because it provides little resistance heat flows dramatically faster through that element.
Parallel Path Method doesn’t work for highly conductive elements.

Because of this, it accounts for a far greater amount of the heat flow than is represented by area, so it cannot be calculated by hand with the parallel path method (weighted average R-value by area).

TABLE A9.2B  Effective Insulation/Framing Layer R-Values for Wall Insulation Installed Between Steel Framing

<table>
<thead>
<tr>
<th>Nominal Depth of Cavity, in.</th>
<th>Actual Depth of Cavity, in.</th>
<th>Rated R-Value of Airspace or Insulation</th>
<th>Effective Framing/Cavity R-Value at 16 in. on Center</th>
<th>Effective Framing/Cavity R-Value at 24 in. on Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty Cavity, No Insulation</td>
<td>4</td>
<td>R-0.91</td>
<td>0.79</td>
<td>0.91</td>
</tr>
<tr>
<td>Insulated Cavity</td>
<td>4</td>
<td>R-11</td>
<td>5.5</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>R-13</td>
<td>6.0</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>R-15</td>
<td>6.4</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>R-19</td>
<td>7.1</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>R-21</td>
<td>7.4</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>R-25</td>
<td>7.8</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Represents 0.4% of the wall area but decreases R-value by 50-70%.
2D Heat Transfer Program:
  - Define section geometry & material properties such as thermal conductance
THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:
- Define section geometry & material properties
- Define surface temperatures & coefficients
THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:
- Define section geometry & material properties
- Define surface temperatures & coefficients
- Define surface(s) to calculate U-value
THERMAL BRIDGING | THERM OVERVIEW

2D Heat Transfer Program:
- Results provided are U-value(s), temperature gradients & heat flow
Windows:

- Extensive glazing library
- Build assemblies
- Define frames and shading elements
- Calculates assembly U-value
- Imports assembly into THERM

Windows is a program that works with THERM for glazing systems. It’s glazing library has almost all glasses commercially available, and you can build assemblies to determine glazing properties like the SHGC, visual transmittance, center of glass U-value (glass only), and assembly u-value (glass & frame). It also exports the assembly and it’s properties into THERM for more detailed analysis.
THERMAL BRIDGING | DISCONTINUOUS ELEMENTS

How to make a 2D program simulate a 3D world:

<table>
<thead>
<tr>
<th>Material</th>
<th>Measured °C</th>
<th>Parallel Path °C</th>
<th>% Different</th>
<th>Measured °C</th>
<th>Isothermal Planes °C</th>
<th>% Different</th>
<th>Averaged °C</th>
<th>% Different</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon, 229mm</td>
<td>12.4</td>
<td>11.5</td>
<td>-7.3%</td>
<td>11.5</td>
<td>-7.3%</td>
<td></td>
<td>11.5</td>
<td>-7.3%</td>
</tr>
<tr>
<td>Stainless, 457mm</td>
<td>11.0</td>
<td>11.3</td>
<td>+2.7%</td>
<td>10.5</td>
<td>-4.5%</td>
<td></td>
<td>10.9</td>
<td>-0.9%</td>
</tr>
<tr>
<td>Stainless, 305mm</td>
<td>10.8</td>
<td>11.2</td>
<td>+3.7%</td>
<td>10.1</td>
<td>-6.5%</td>
<td></td>
<td>10.7</td>
<td>-0.9%</td>
</tr>
<tr>
<td>Stainless, 229mm</td>
<td>10.7</td>
<td>11.1</td>
<td>+3.7%</td>
<td>9.8</td>
<td>-8.4%</td>
<td></td>
<td>10.5</td>
<td>-1.9%</td>
</tr>
<tr>
<td>Stainless, 152mm</td>
<td>10.5</td>
<td>10.9</td>
<td>+3.8%</td>
<td>9.2</td>
<td>-12.4%</td>
<td></td>
<td>10.1</td>
<td>-3.8%</td>
</tr>
<tr>
<td>Stainless, 76mm</td>
<td>9.4</td>
<td>10.3</td>
<td>+9.6%</td>
<td>7.9</td>
<td>-16.0%</td>
<td></td>
<td>9.1</td>
<td>-3.2%</td>
</tr>
<tr>
<td>Steel, 229mm</td>
<td>8.8</td>
<td>11.1</td>
<td>+26.1%</td>
<td>7.7</td>
<td>-12.5%</td>
<td></td>
<td>9.4</td>
<td>+6.8%</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±8.1%</td>
<td></td>
<td>±3.5%</td>
</tr>
</tbody>
</table>

THERM is a 2D simulation engine, but heat flow is 3D. Therefore, THERM cannot accurately account for discontinuous bridging elements (like bolts), but is accurate for continuous elements (like studs). Work around methods have been developed to allow it to reasonably simulate discontinuous elements. One method, the parallel path method, underestimates the heat flow, while the other, the isothermal planes method, overestimates it. If you average the results of the 2 methods, they are much closer to the real world results.
THERMAL BRIDGING | DISCONTINUOUS ELEMENTS

Parallel Path Method
- Weighted average of 2 simulations

\[ U_P = F_B \times U_B + F_N \times U_N \]

Whereas, \( U_P \) = U-value parallel path
\( F_B \) = Fraction of bridging element
\( U_B \) = U-value from THERM with bridging element
\( F_N \) = Fraction of clear wall
\( U_N \) = U-value from THERM of clear wall

The parallel path method requires 2 simulations. One with the discontinues bridging element, and one without it. A weighted average by area of the 2 calculated U-values is then taken to combine them.
Parallel Path Method
– 1 simulation with a weighted average of the conductivities

\[ k_{\text{eff}} = F_B \times k_B + F_N \times k_N \]

Whereas, \( U_I = \) U-value from THERM using isothermal planes method

\( k_B = \) effective conductivity

\( k_B = \) conductivity of bridging element

\( k_N = \) conductivity of non-bridging element

The isothermal planes method requires 1 simulation. A weighted average by area of the thermal conductivity of the bridging element and the insulation is taken to determine an effective conductance. The simulation is run with this value for the discontinuous element.
Example R-value results for a metal M-tie from the 3 runs for the two methods described.
For an example that can be calculated with the revised zone method (Lee & Pessiki, 2008) for validation, the averaged results from the 2 THERM simulation methods differed by less than 3%.

<table>
<thead>
<tr>
<th>Wall Fraction</th>
<th>U-Value (W/m²°K)</th>
<th>Difference from Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>Parallel Path, Clear Wall</td>
<td>0.99</td>
<td>0.51</td>
</tr>
<tr>
<td>Parallel Path, M-Tie</td>
<td>0.01</td>
<td>2.43</td>
</tr>
<tr>
<td>Parallel Path, Combined</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td>Isothermal Planes</td>
<td>1</td>
<td>0.64</td>
</tr>
<tr>
<td>Averaged U-Value</td>
<td>1</td>
<td>0.58</td>
</tr>
</tbody>
</table>
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THERMAL BRIDGING | VA BROCKTON MENTAL HEALTH

THERM was used to analyze the heat flow through the renovation of an existing façade. The simulation highlighted that having no insulation over the heated basement, and thermal bridges in the design significantly decreased the thermal performance from the design intent.
A number of alternate designs were investigated to improve the thermal performance of the design, and create a more continuous thermal barrier. In existing conditions, it is often impossible to eliminate all thermal bridges.
<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Proposed Alternative Design #2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calculated R-Value</td>
<td>Simulated R-Value</td>
</tr>
<tr>
<td>Roof</td>
<td>29.1</td>
<td>22.1</td>
</tr>
<tr>
<td>Walls</td>
<td>15.9</td>
<td>9.1</td>
</tr>
<tr>
<td>Floor</td>
<td>3.5 + ground</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Even still, with a few changes, a dramatic improvement in the R-value of the assemblies can be seen.
## Heat Loss @ Winter Design Conditions

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Proposed Alternative Design #2</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Loss @ Winter Design Conditions</td>
<td>370.2 Btu/h·ft</td>
<td>213.7 Btu/h·ft</td>
<td>- 42%</td>
</tr>
</tbody>
</table>

### Breakdown of Heat Loss

<table>
<thead>
<tr>
<th>Component</th>
<th>Original Design</th>
<th>Proposed Alternative Design #2</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>29%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Wall</td>
<td>32%</td>
<td>38%</td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td>39%</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

Reminder: R-value is h·ft²·°F/Btu

This resulted in a significant decrease in the heat lost in the building.
This analysis investigated a concrete slab that created an overhang for exterior shading. Alternative options to insulate the slab were investigated.
The best performing option was to have a thermally broken system like this one.
Terminating the slab at the façade and having a folded metal panel with insulation was investigated, but thermal bridges occurring at the joins and at the storefront mullions dramatically decreased performance.
This spandrel panel option does not perform well, because there is a large amount of heat lost through the mullions.
In addition to determining the U-value, THERM can also be used to determine potential condensation conditions. Given the tight temperature and humidity ranges in this museum, condensation would occur at 55°F.
Alternative options to thermally break the davit from the interior structure were investigated.
Some conditions also require exterior insulation.
Heat flow simulations can also be a quick way to understand discrepancies between the design intent and proposed design details, such as with this metal panel curtain wall.
THERMAL BRIDGING | RESOURCES

Program

– Documentation & Tutorials:
  http://windows.lbl.gov/software/window/6/w6_docs.htm
– Steel Studs:
THERMAL BRIDGING | RESOURCES

Material Conductivity
- [http://www.coloradoenergy.org/procorner/stuff/r-values.htm](http://www.coloradoenergy.org/procorner/stuff/r-values.htm)
- ASHRAE Handbook of Fundamentals

Air Film Coefficients
- ASHRAE Handbook of Fundamentals

Climate Conditions
- EPW Weather Files: [http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm](http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm)
THANK YOU.