Thermal Bridging and the 2024 IECC

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Foam Plastic Applications for Better Building

Outline

Review Thermal Envelope Compliance
(Commercial Building Walls)

2024 IECC Thermal Bridging Requirements

- What is a thermal bridge?
- Why address thermal bridges?
- How to mitigate thermal bridges?

Conclusions

Bibliography (design resources)

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Learning Objectives

- Learn the building envelope insulation requirements in the 2024 IECC
- Be equipped to define and identify thermal bridges in accordance with the 2024 IECC
- Gain knowledge to help comply with new 2024 IECC provisions for mitigation of thermal bridges at building assembly and component interfaces
- Learn how to apply prescriptive and performance-based thermal bridging solutions to allow for design flexibility, trade-offs, and optimization.

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Course Description

The 2024 International Energy Conservation Code (IECC) provisions for commercial building energy efficiency (including Group R residential buildings > 3 stories) contains a number of significant changes affecting building enclosure design, especially for thermal bridging. This presentation will briefly review the 2024 IECC insulation requirements and focus on the new thermal bridging requirements (prescriptive and performance) in the 2024 IECC and relate them to similar requirements in the ASHRAE 90.1-2022 standard where appropriate. In addition to explaining these new code provisions, typical details and solutions for compliance will be featured and supplemented with actionable resources to facilitate practical results.

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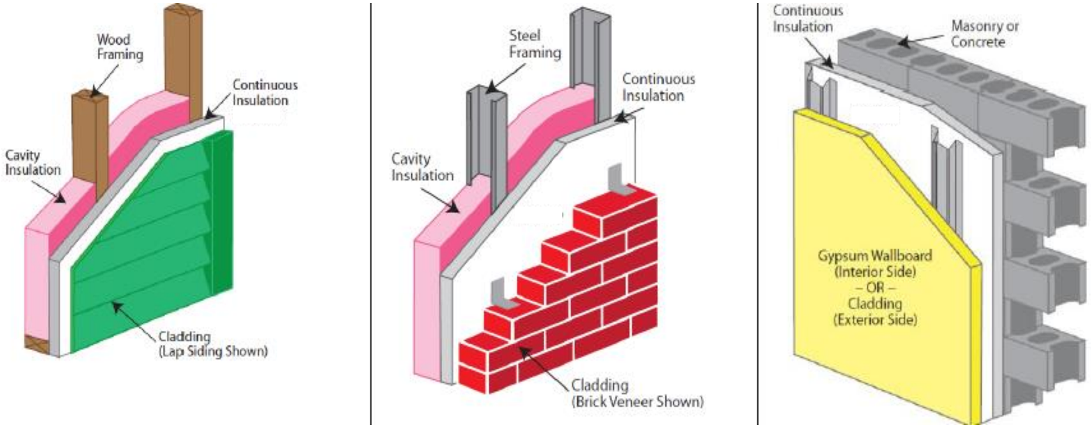
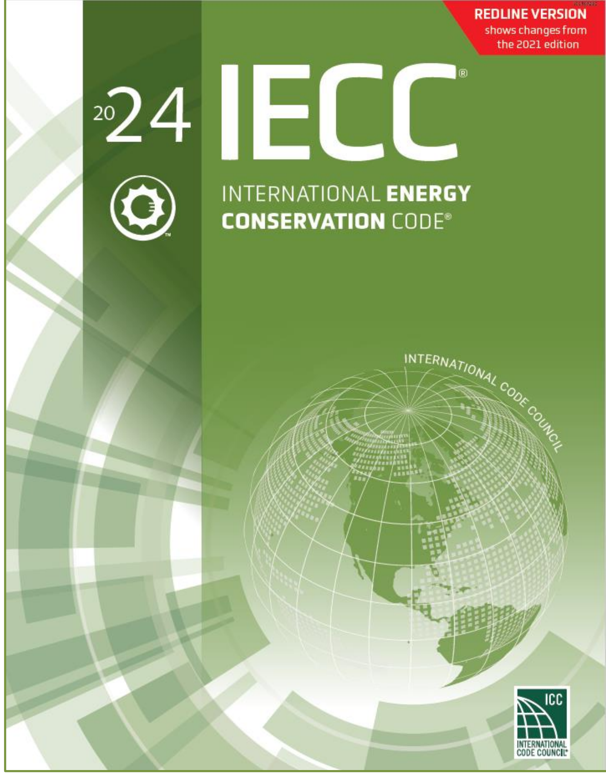
2024 IECC – Thermal Envelope Compliance

- Climate Zones
- Compliance paths/options
- Prescriptive U-factors & R-values (e.g., walls)



Source: ABTG



https://codes.iccsafe.org/content/IECC2024P1

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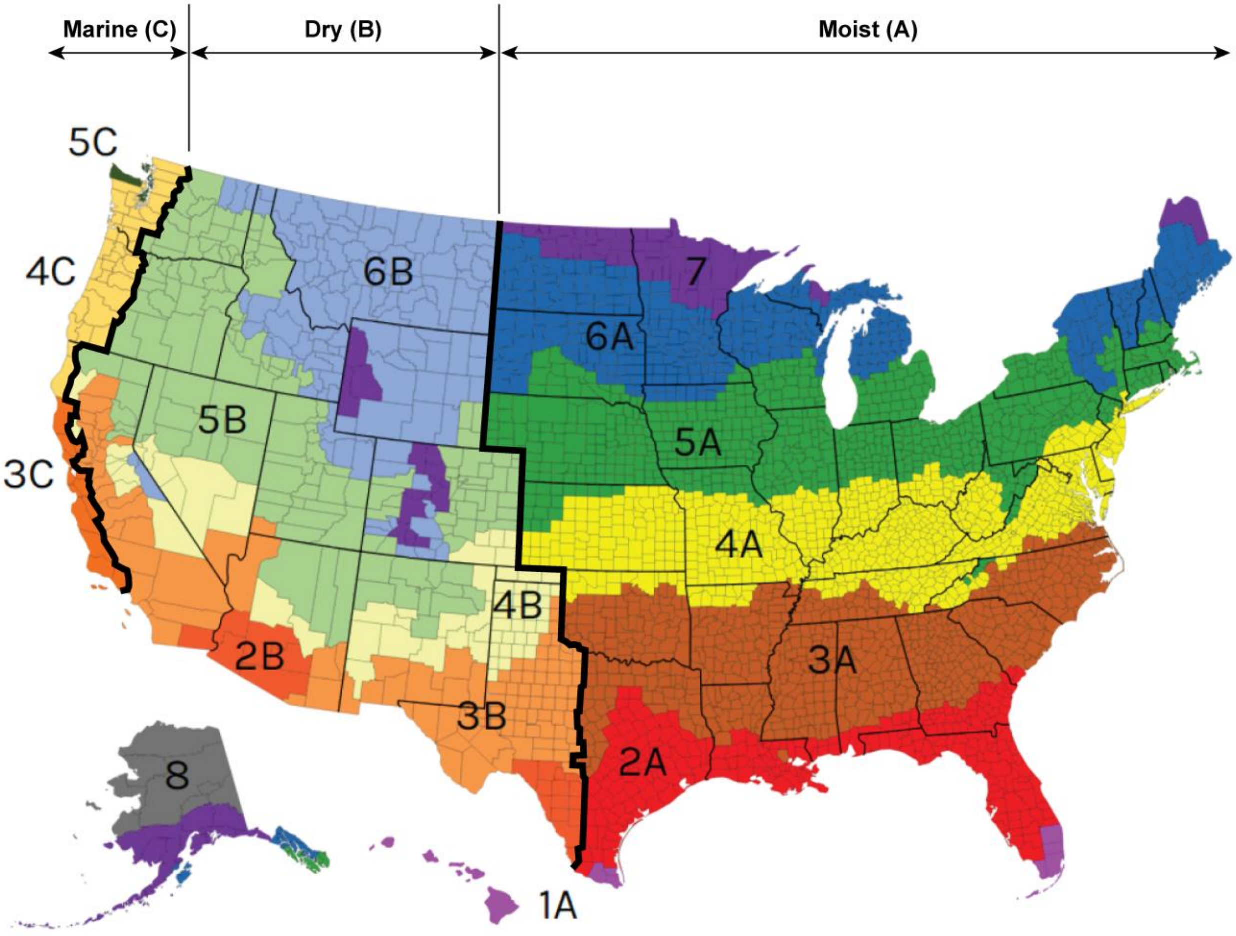

Source: DOE (consistent with IECC Figure C301.1)

Determine Your Climate Zone (C301)

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Choose Your Compliance Path (C401)

1. **Prescriptive Compliance** (C401.2.1(1))

    C402 Building Thermal Envelope Requirements

    + Opaque BTE insulation compliance options (C402.2):
        - U-factor Method (C402.1.2)
        - R-value Method (C402.1.3)
        - Component Performance Method (C402.1.4)
            - Includes thermal bridging factors ← **New in 2024**
    + Wall & Roof solar reflectance (C402.3, C402.4)
    + Fenestration U-factor & SHGC (C402.5)
    + Air leakage (C402.6)
    + Thermal Bridges in Above-Grade Walls (C402.7) ← **New in 2024**

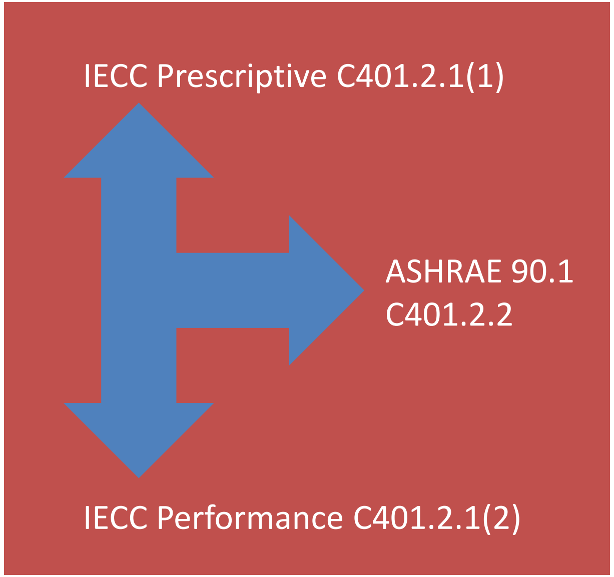
    C403 Mechanical Systems / C404 Service Water Heating / C405 Electric Power & Lighting / C406 Additional Efficiency Credits / C408 Maintenance & Commissioning

2. **Total Building Performance** (C401.2.1(2) & Section C407)

    Includes modeling of thermal bridges ← **New in 2024**

3. **ASHRAE 90.1-2022**

    Similar to 2024 IECC and includes similar thermal bridging requirements



Prescriptive R-value & U-factor Requirements for Walls

2024 IECC-C Tables C402.1.2 & C402.1.3 (prior - Tables C402.1.3 & C402.1.4)

<table>
<tr><th rowspan="2">Climate Zone</th><th rowspan="2">Building Use</th><th>Mass</th><th colspan="3">Metal Framed</th><th colspan="3">Wood Framed</th></tr>
<tr><th>2018 - 2024 IECC</th><th>2018 IECC</th><th>2021 IECC</th><th>2024 IECC</th><th>2018 IECC</th><th>2021 IECC</th><th>2024 IECC</th></tr>
<tr><td rowspan="2">0 and 1</td><td>All other</td><td rowspan="3">R-5.7ci
(U-0.151)</td><td rowspan="3">R13+5ci
(U-0.077)</td><td rowspan="3">R13+5ci
(U-0.077)</td><td rowspan="3">R0+10ci or
R13+5ci or
R20+3.8ci
(U-0.077)</td><td rowspan="9">R13+3.8ci or
R20
(U-0.064)</td><td rowspan="8">R13+3.8ci or
R20
(U-0.064)</td><td rowspan="8">R0+12ci or
R13+3.8ci or
R20
(U-0.064)</td></tr>
<tr><td>Group R</td></tr>
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<tr><td>Group R</td><td rowspan="2">R-7.6ci
(U-0.123)</td><td rowspan="10">R13+7.5ci
(U-0.064)</td><td rowspan="5">R13+7.5ci
(U-0.064)</td><td rowspan="5">R0+12.6ci or
R13+7.5ci or
R20+6.3ci
(U-0.064)</td></tr>
<tr><td rowspan="2">3</td><td>All other</td></tr>
<tr><td>Group R</td><td rowspan="2">R-9.5ci
(U-0.104)</td></tr>
<tr><td rowspan="2">4 Except Marine</td><td>All other</td></tr>
<tr><td>Group R</td><td rowspan="2">R-11.4ci
(U-0.090)</td></tr>
<tr><td rowspan="2">5 and Marine 4</td><td>All other</td><td rowspan="2">R13+10ci
(U-0.055)</td><td rowspan="2">R0+15.2ci or
R13+10ci or
R20+9ci
(U-0.055)</td><td rowspan="6">R13+7.5ci or
R20+3.8ci
(U-0.051)</td><td rowspan="6">R0+16ci or
R13+7.5ci or
R20+3.8ci or
R27
(U-0.051)</td></tr>
<tr><td>Group R</td><td rowspan="2">R-13.3ci
(U-0.080)</td><td rowspan="5">R13+7.5ci or
R20+3.8ci
(U-0.051)</td></tr>
<tr><td rowspan="2">6</td><td>All other</td><td rowspan="3">R13+12.5ci
(U-0.049)</td><td rowspan="3">R0+17.3ci or
R13+12.5ci or
R20+11ci
(U-0.049)</td></tr>
<tr><td>Group R</td><td rowspan="3">R-15.2ci
(U-0.071)</td></tr>
<tr><td rowspan="2">7</td><td>All other</td></tr>
<tr><td>Group R</td><td>R13+15.6ci
(U-0.052)</td><td>R13+15.6ci
(U-0.042)</td><td>R0+21ci or
R13+15.6ci or
R20+14.3ci
(U-0.042)</td></tr>
<tr><td rowspan="2">8</td><td>All other</td><td rowspan="2">R-25ci
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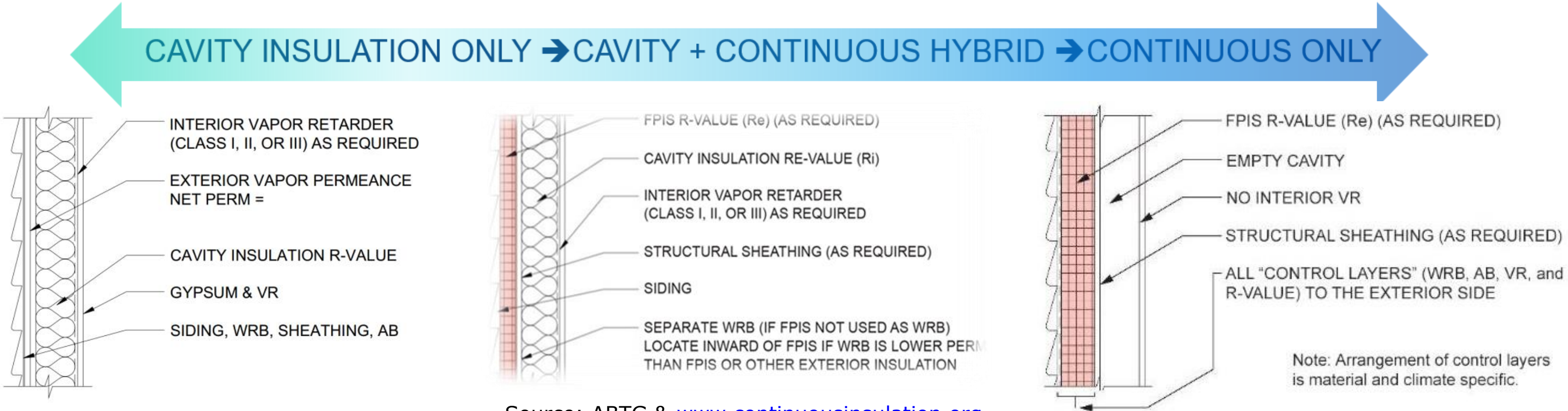
(U-0.036)</td><td rowspan="2">R13+18.8ci
(U-0.032)</td><td rowspan="2">R0+27.5ci or
R13+18.8ci or
R20+14ci
(U-0.032)</td></tr>
<tr><td>Group R</td><td>R13+17.5ci
(U-0.045)</td></tr>
</table>

Typical Methods for Insulating Exterior Walls

1. Cavity insulation only (traditional method)
2. Cavity insulation + continuous insulation (common choice for modern code-compliant or high-performance walls)
3. Continuous insulation (ci) only (the "perfect wall" with all control layers to the exterior – maximum protection and thermal performance)



Source: ABTG & www.continuousinsulation.org

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Continuous Insulation (ci)

Insulation that is **uncompressed***

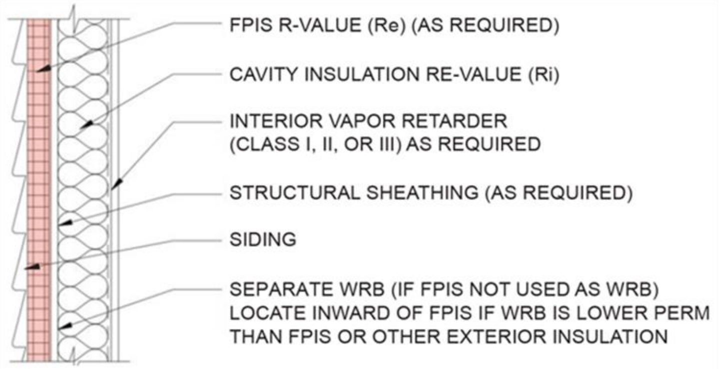
… and **continuous** across all structural members

… **without thermal bridges** other than fasteners and service openings.

(IBC, IRC, IECC and ASHRAE 90.1* definition)

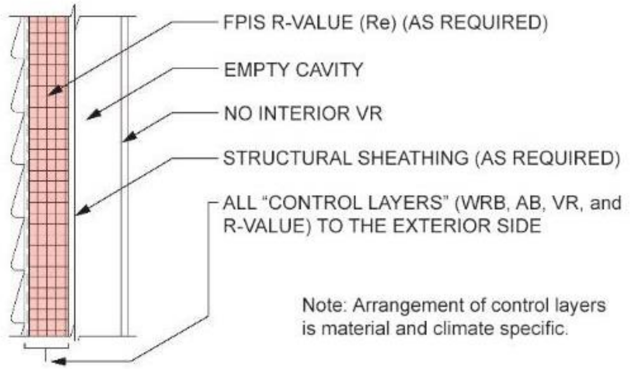
HYBRID ASSEMBLIES

Cavity + Continuous + Interior VR



"PERFECT WALL" ASSEMBLIES

Continuous Only (no Interior VR)



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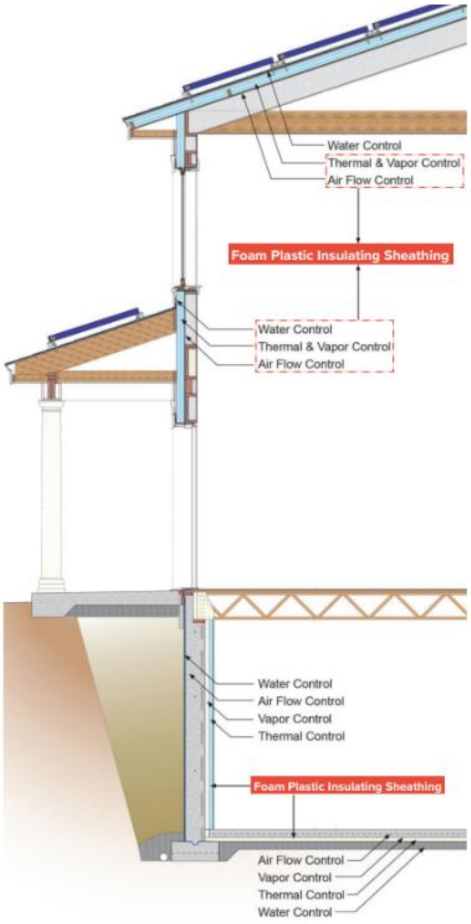
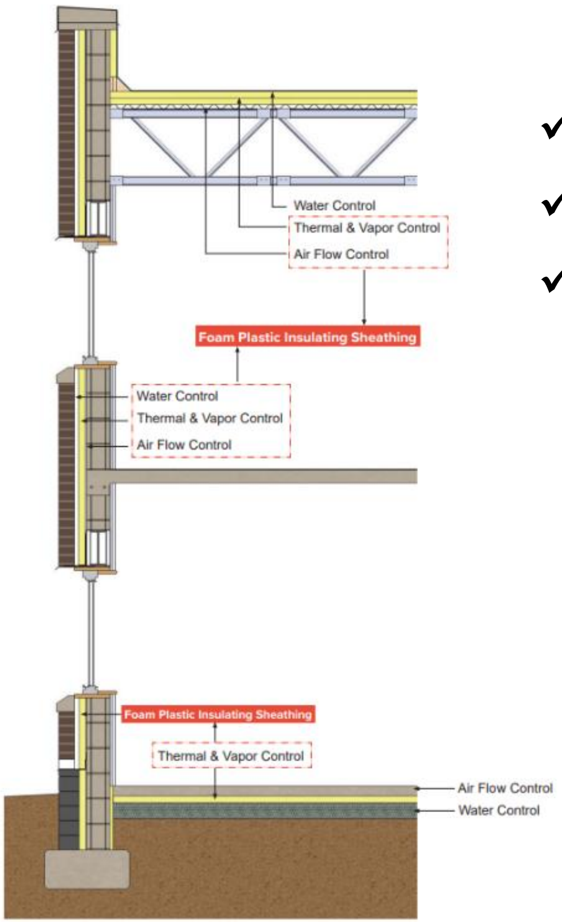
2024 IECC –Thermal Bridging Requirements

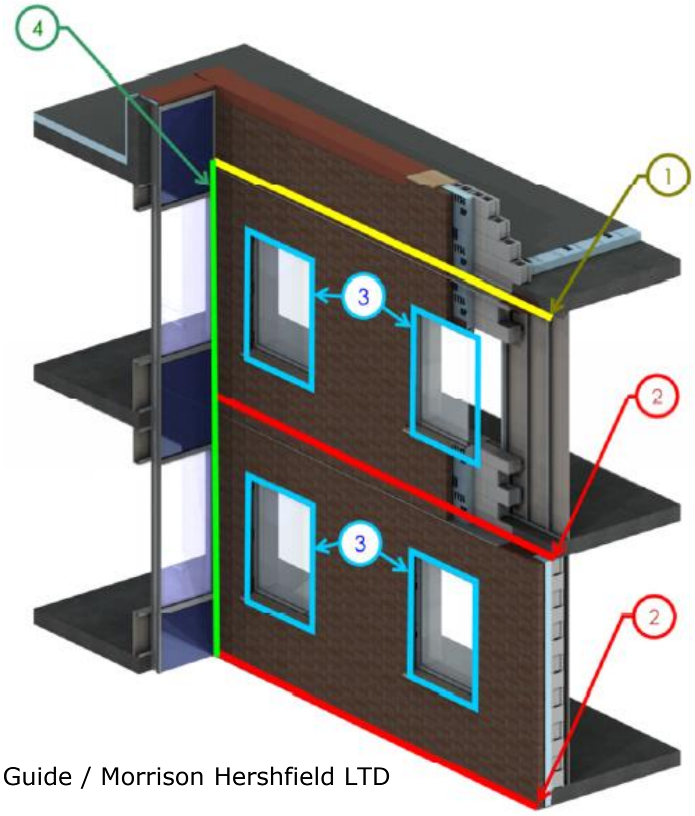




- ✓ What is a thermal bridge?
- ✓ Why address them?
- ✓ How to comply?

What is a thermal bridge? (Three Types)

- ✓ Clear-field thermal bridge
- ✓ Linear thermal bridge
- ✓ Point thermal bridge



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

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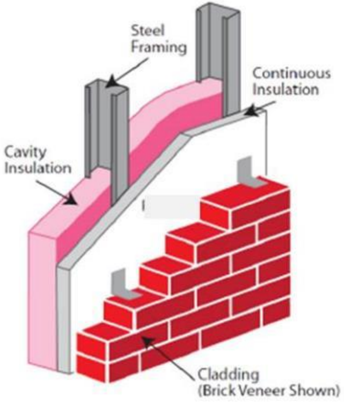
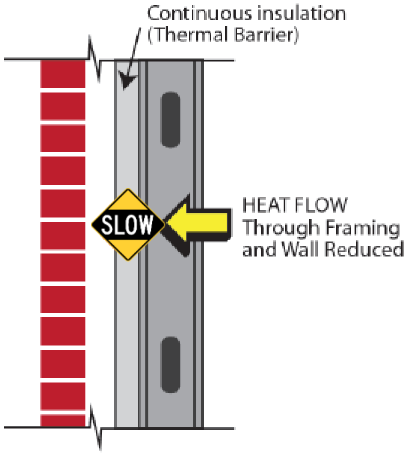
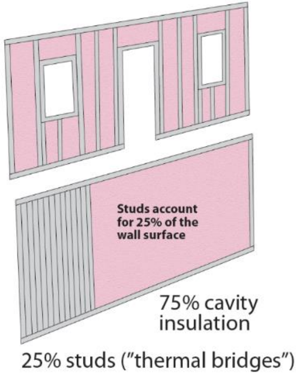
Clear-Field Thermal Bridge

- Thermal bridges distributed over entire area of an opaque BTE assembly that interrupts cavity or integral insulation.
- Addressed in assembly U-factor calculations for code compliance (which prescriptive R-values are based on).
- U-factor varies with amount of framing ("framing factor")
- Impact:
  - Cavity insulation in steel framing is only ~35-50% effective relative to the cavity insulation's rated R-value.
  - Cavity insulation in wood framing is roughly 85% effective.
- Generally, small distributed elements such as fasteners and brick ties can increase a wall U-factor from 1% to 40% depending on wall type, attachment schedule and material properties, insulation configuration, etc.)
  - Not currently a code-compliance requirement







Clear-Field Thermal Bridge – ci mitigation

	U-factor Comparison		
Wall Component	R20	R25	R20+5ci
Outside winter air	0.17	0.17	0.17
Siding	0.62	0.62	0.62
Continuous insulation	0	0	5
OSB - 7/16	0.62	0.62	0.62
SPF stud	6.875	6.875	6.875
SPF header	6.875	6.875	6.875
Cavity insulation	20	25	20
1/2 drywall	0.45	0.45	0.45
Inside air film	0.68	0.68	0.68
R-value stud path	9.42	9.42	14.42
R-value header path	9.42	9.42	14.42
R-value cavity path	22.54	27.54	27.54
Framing factor - studs	21%	21%	21%
Framing factor -header	4%	4%	4%
Framing factor - cavity	75%	75%	75%
U-factor	**0.060**	**0.054**	**0.045**
Effective R of wall	**17**	**19**	**22**

R25 ≠ R20 + 5ci

The R20+5ci wall is 15% more efficient than the R-25 wall (U-0.045 vs. U-0.054).

This demonstrates that R-value of cavity and continuous insulation cannot be simply added (and this is prohibited as a means of compliance).

Cavity Insulation Only

Cavity + Ci Insulation

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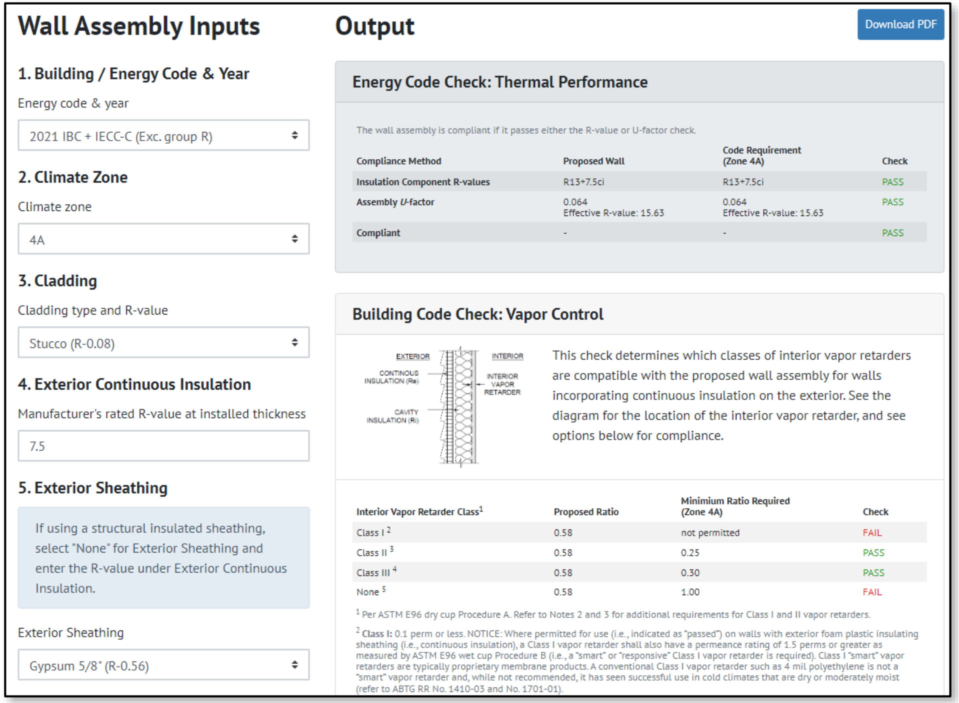
Clear-Field Thermal Bridge – Resources



Wall Assembly Inputs

1. Building / Energy Code & Year

Energy code & year

2021 IBC + IECC-C (Exc. group R)

2. Climate Zone

Climate zone

4A

3. Cladding

Cladding type and R-value

Stucco (R-0.08)

4. Exterior Continuous Insulation

Manufacturer's rated R-value at installed thickness

7.5

5. Exterior Sheathing

If using a structural insulated sheathing, select "None" for Exterior Sheathing and enter the R-value under Exterior Continuous Insulation.

Exterior Sheathing

Gypsum 5/8" (R-0.56)

Output

Download PDF

Energy Code Check: Thermal Performance

The wall assembly is compliant if it passes either the R-value or U-factor check.

Compliance Method	Proposed Wall	Code Requirement (Zone 4A)	Check
Insulation Component R-values	R13+7.5ci	R13+7.5ci	PASS
Assembly *U*-factor	0.064 Effective R-value: 15.63	0.064 Effective R-value: 15.63	PASS
Compliant	-	-	PASS

Building Code Check: Vapor Control

This check determines which classes of interior vapor retarders are compatible with the proposed wall assembly for walls incorporating continuous insulation on the exterior. See the diagram for the location of the interior vapor retarder, and see options below for compliance.

Interior Vapor Retarder Class[1]	Proposed Ratio	Minimum Ratio Required (Zone 4A)	Check
Class I [2]	0.58	not permitted	FAIL
Class II [3]	0.58	0.25	PASS
Class III [4]	0.58	0.30	PASS
None [5]	0.58	1.00	FAIL

[1] Per ASTM E96 dry cup Procedure A. Refer to Notes 2 and 3 for additional requirements for Class I and II vapor retarders.

[2] **Class I:** 0.1 perm or less. NOTICE: Where permitted for use (i.e., indicated as "passed") on walls with exterior foam plastic insulating sheathing (i.e., continuous insulation), a Class I vapor retarder shall also have a permeance rating of 1.5 perms or greater as measured by ASTM E96 wet cup Procedure B (i.e., a "smart" or "responsive" Class I vapor retarder is required). Class I "smart" vapor retarders are typically proprietary membrane products. A conventional Class I vapor retarder such as 4 mil polyethylene is not a "smart" vapor retarder and, while not recommended, it has seen successful use in cold climates that are dry or moderately moist (refer to ABTG RR No. 1410-03 and No. 1701-01).

- Design Tool: Steel & Wood Frame Wall Calculators
  - Performs U-factor and water vapor control design checks for coordinated energy code and building code compliance
- Free online tool available!
  - continuousinsulation.org/calculators/

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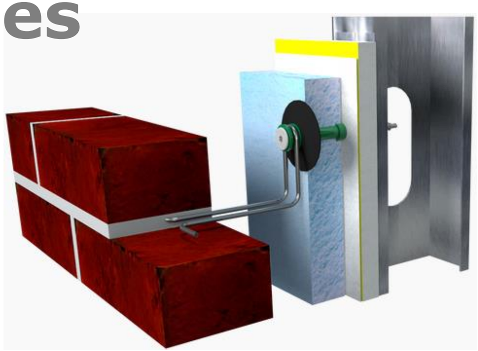
Mitigating Clear-Field Thermal Bridges

Some ways to mitigate clear field thermal bridges include:

- Apply continuous insulation over structure/framing members (minimize discontinuity at floor/wall/roof intersections)
- Reduce "framing factor" where structurally feasible (wider frame spacing, double stud framing, etc.)
- Use low conductivity structural materials
- Mount metal/wood furring over (not through) continuous insulation layer
  - If furring penetrates through the exterior insulation, the exterior insulation is NOT continuous insulation and an appropriately increased U-factor for the wall must be determined for compliance.
- Use low conductivity fasteners or devices to attach cladding, furring, etc. to framing (e.g., stainless steel, carbon fiber, thermally-broken brick ties, etc.)
  - Not a code requirement, but good practice



https://www.trufastwalls.com/thermal-grip-masonry-veneer-anchor

Fig1: Solid metal fastening solution

Fig. 2: Version with plastic sleeve and shorter fastener

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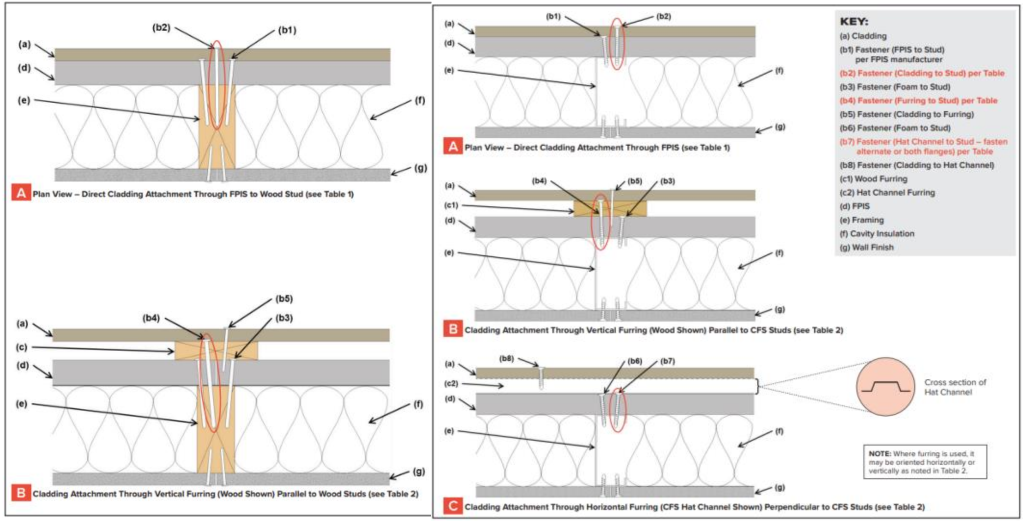
Cladding & Furring Attachment through Foam Plastic Insulating Sheathing (FPIS) Continuous Insulation (ci)

For code-compliant fastening of cladding and furring through continuous insulation, see 2024 IBC Section 1404.5 and resources at https://www.continuousinsulation.org/cladding-connections



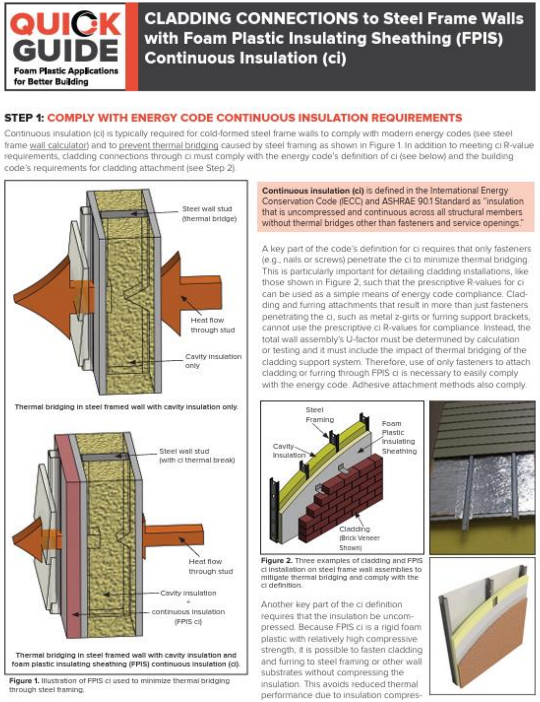
A Plan View – Direct Cladding Attachment Through FPIS to Wood Stud (see Table 1)

B Cladding Attachment Through Vertical Furring (Wood Shown) Parallel to Wood Studs (see Table 2)

A Plan View – Direct Cladding Attachment Through FPIS (see Table 1)

B Cladding Attachment Through Vertical Furring (Wood Shown) Parallel to CFS Studs (see Table 2)

C Cladding Attachment Through Horizontal Furring (CFS Hat Channel Shown) Perpendicular to CFS Studs (see Table 2)


QUICK GUIDE
Foam Plastic Applications for Better Building

CLADDING CONNECTIONS to Steel Frame Walls with Foam Plastic Insulating Sheathing (FPIS) Continuous Insulation (ci)

STEP 1: COMPLY WITH ENERGY CODE CONTINUOUS INSULATION REQUIREMENTS

Continuous insulation (ci) is typically required for cold-formed steel frame walls to comply with modern energy codes (see steel frame wall calculator) and to prevent thermal bridging caused by steel framing as shown in Figure 1. In addition to meeting ci R-value requirements, cladding connections through ci must comply with the energy code's definition of ci (see below) and the building code's requirements for cladding attachment (see Step 2).

Steel wall stud (thermal bridge)
Heat flow through stud
Cavity insulation only

Thermal bridging in steel framed wall with cavity insulation only.

Steel wall stud (with ci thermal break)
Heat flow through stud
Cavity insulation + continuous insulation (FPIS ci)

Thermal bridging in steel framed wall with cavity insulation and foam plastic insulating sheathing (FPIS) continuous insulation (ci).

Figure 1. Illustration of FPIS ci used to minimize thermal bridging through steel framing.

Continuous insulation (ci) is defined in the International Energy Conservation Code (IECC) and ASHRAE 90.1 Standard as "insulation that is uncompressed and continuous across all structural members without thermal bridges other than fasteners and service openings."

A key part of the code's definition for ci requires that only fasteners (e.g., nails or screws) penetrate the ci to minimize thermal bridging. This is particularly important for detailing cladding installations, like those shown in Figure 2, such that the prescriptive R-values for ci can be used as a simple means of energy code compliance. Cladding and furring attachments that result in more than just fasteners penetrating the ci, such as metal z-girts or furring support brackets, cannot use the prescriptive ci R-values for compliance. Instead, the total wall assembly's U-factor must be determined by calculation or testing and it must include the impact of thermal bridging of the cladding support system. Therefore, use of only fasteners to attach cladding or furring through FPIS ci is necessary to easily comply with the energy code. Adhesive attachment methods also comply.

Steel Framing
Cavity Insulation
Foam Plastic Insulating Sheathing
Cladding (Brick Veneer Shown)

Figure 2. Three examples of cladding and FPIS ci installation on steel frame wall assemblies to mitigate thermal bridging and comply with the ci definition.

Another key part of the ci definition requires that the insulation be uncompressed. Because FPIS ci is a rigid foam plastic with relatively high compressive strength, it is possible to fasten cladding and furring to steel framing or other wall substrates without compressing the insulation. This avoids reduced thermal performance due to insulation compres-

Linear Thermal Bridge

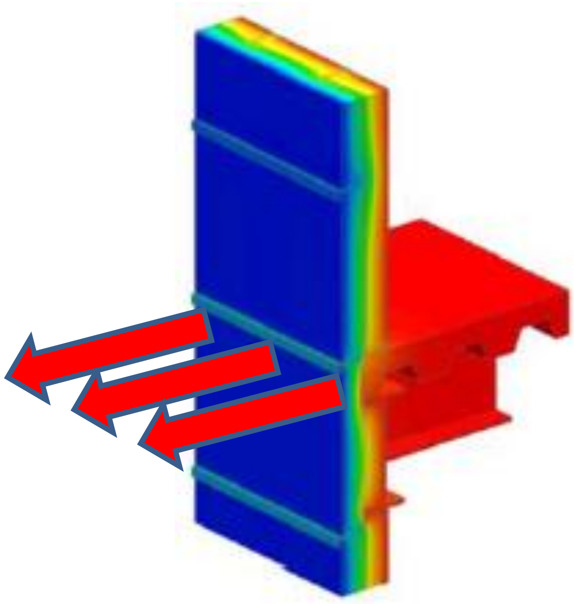
Additional heat flow caused by details that can be defined by a length along the building surface.

- Units for “Psi-factor” (Ψ) – linear thermal transmittance:
  [IP] Btu / hr-ft-°F
  [SI] W / m-K

Usually associated with the intersection of different building thermal envelope assemblies and components.

These are not accounted for in the clear-field U-factors and R-values used to demonstrate compliance of building thermal envelope assemblies.

- They must be uniquely considered in their impact to the overall building thermal envelope



Linear Thermal Transmittance

Source: Morrison Hershfield LTD / ASHRAE RP 1365

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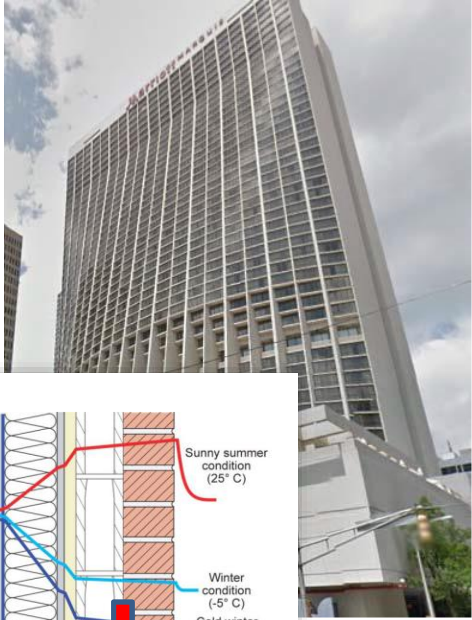
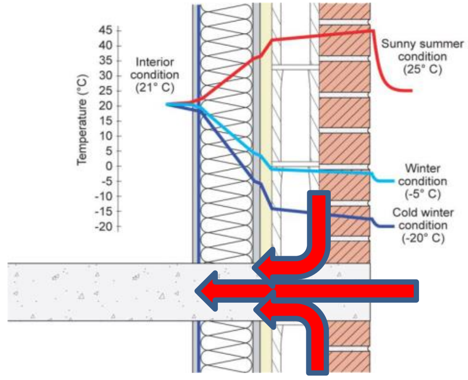
Linear Thermal Bridge

- **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!
  - They are not accounted for in the energy codes' assembly U-factors and R-values!
  - Also not accounted for in fenestration rated U-factors



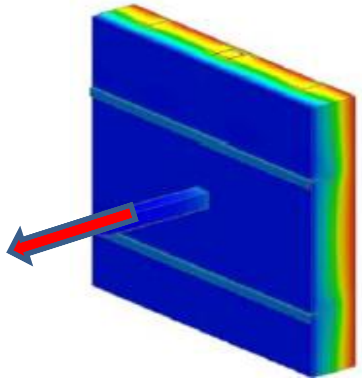


Source: USACE report

Point Thermal Bridge

- Heat flow caused by a thermal bridge that occurs at single element or discrete "point"
  - Units for "Chi-factor" (χ) – point thermal transmittance:
    [IP]   Btu / hr-°F
    [SI]   W / K

- **Examples:**
  Beams, columns, and mechanical equipment 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 "clear-field" U-factor calculation if distributed uniformly and repetitively over the surface area of an assembly



Point Thermal Transmittance

Source: Morrison Hershfield LTD / ASHRAE RP 1365

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Point Thermal Bridge

- **Impact:**
  Assembly U-factor increases by 1% to 40% depending on amount of insulation penetrated, size and spacing of penetrations, type of structure (e.g., wood, steel, concrete), penetrating material conductivity (e.g., aluminum vs. carbon steel vs. stainless steel), 3-D geometry, etc.
  - **Note:** Stainless steel has 3x lower thermal conductivity than carbon steel and 5x lower thermal conductivity than aluminum

- We'll talk more about mitigating linear and "big" point thermal bridges later…

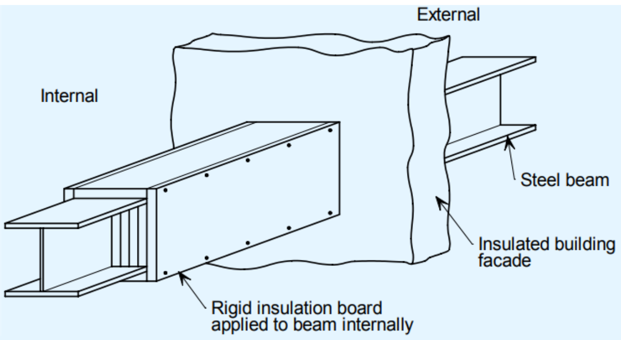

Figure 2.2 *Locally insulated beam*

Avoidance of Thermal Bridging in Steel Construction
https://www.steelconstruction.info/images/5/53/SCI_P380.pdf

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Why address thermal bridges?

- Unaccounted thermal bridges can result in significantly over-estimated building performance (under-estimated energy use).
- 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)

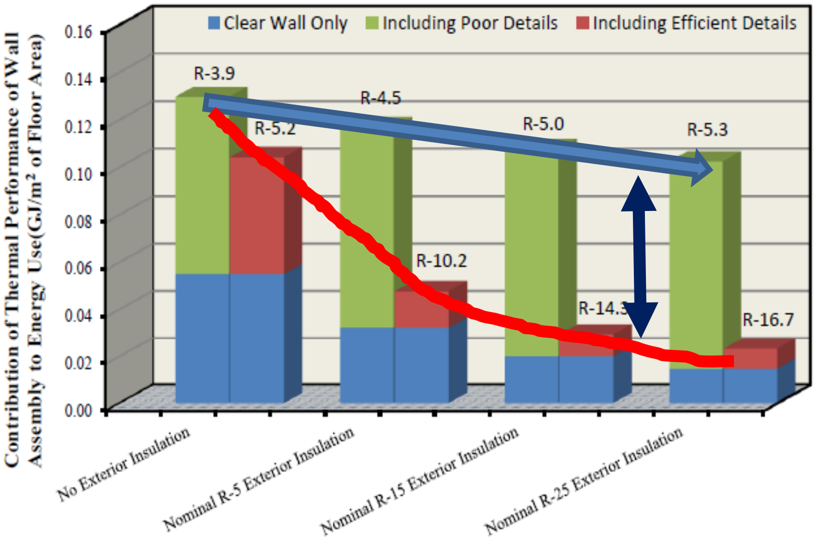

Figure 4.7: Additional building energy use based on thermal performance of the building wall assembly for varying amounts of nominal exterior insulation for a mid-rise MURB in Edmonton (overall assembly thermal resistance in $ft^2 \cdot °F \cdot h/Btu$ also given)

Source: Morrison Hershfield Ltd

CONCLUSION: Use of continuous insulation with good detailing is generally the most efficient way to mitigate thermal bridges.

- Simply adding more insulation to compensate (without mitigating thermal bridges) is another approach, but generally is a much less efficient use of insulation.

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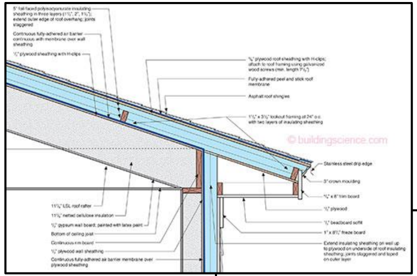
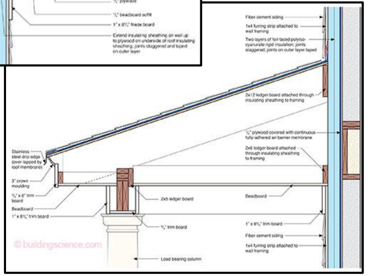
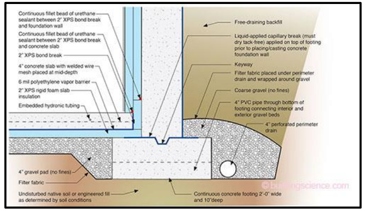
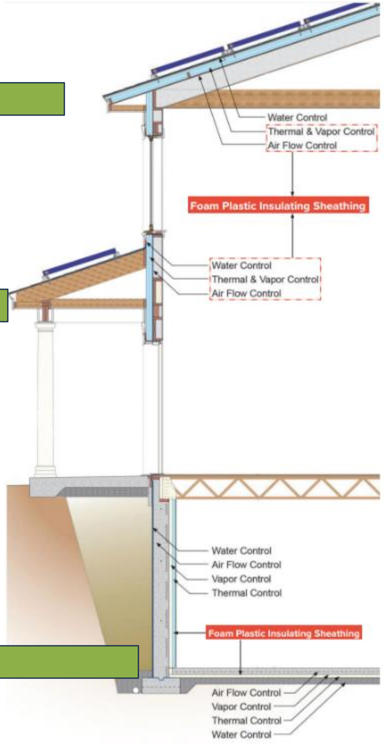
Insulation Continuity = Minimized Thermal Bridges = Maximum Performance of Building Thermal Envelope

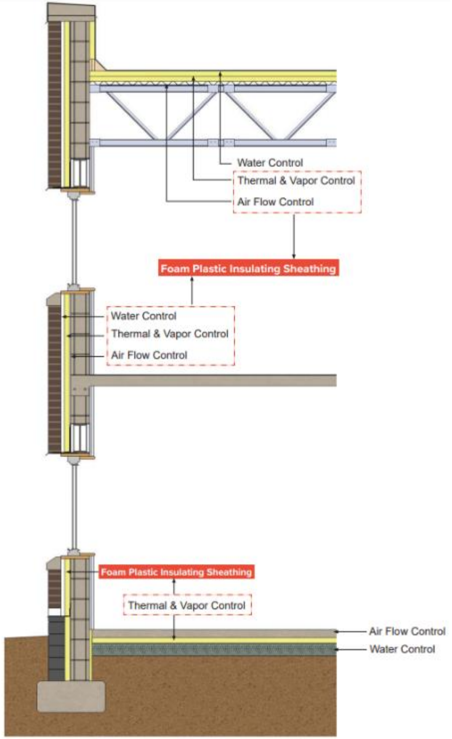




Example Details from BSI-081: Zeroing In (J. Lstiburek, Building Science Corp) as used on NIST NZERTF Project







How to mitigate thermal bridging?

Comply with 2024 IECC code!

- ✓ Focuses on the “big” thermal bridges (not exhaustive)
- ✓ Provides practical prescriptive details (does not require “ideal” or best-performing practices)
- ✓ Allows alternative detailing solutions with at least equivalent performance (e.g., designed details or proprietary devices)
- ✓ Allows trade-offs of thermal bridging performance

2024 IECC-C Thermal Bridging Requirements

- ✓ **C105 Construction Documents**
- ✓ **C107 Inspections**
- ✓ **C202 Definitions**
- ✓ **C402.7 Thermal bridges in above-grade walls (prescriptive)**
  - C402.7.1 Balconies and floor decks
  - C402.7.2 Cladding supports
  - C402.7.3 Structural beams and columns
  - C402.7.4 Vertical fenestration
  - C402.7.5 Parapets
  - C402.1.2.1.8 Mechanical equipment penetrations
- ✓ **C402.1.4 Component performance method (prescriptive trade-offs)**
  - Total UA (thermal conductance) trade-off method, including thermal bridges
- ✓ **C407 Simulated Building Performance**
  - Table C407.4.1(1) – includes thermal bridging modeling requirements

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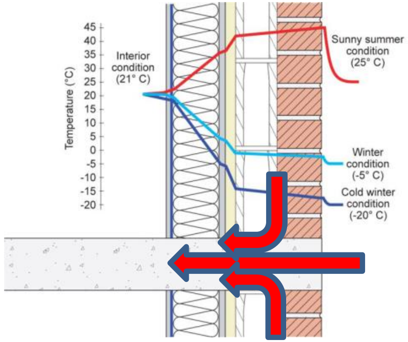
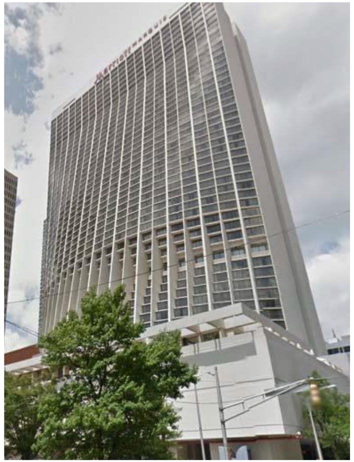
C105 Construction Documents



C105.2 Information on construction documents

1. Energy compliance path.
2. Insulation materials and their *R*-values.
3. *Fenestration* U-factors and solar heat gain coefficients (SHGCs).
4. Area-weighted *U*-factor and solar heat gain coefficient (SHGC) calculations.
5. *Air barrier* and air sealing details, including the location of the *air barrier.*
6. Thermal bridges as identified in Section C402.7.

Etc.



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C107 Inspections

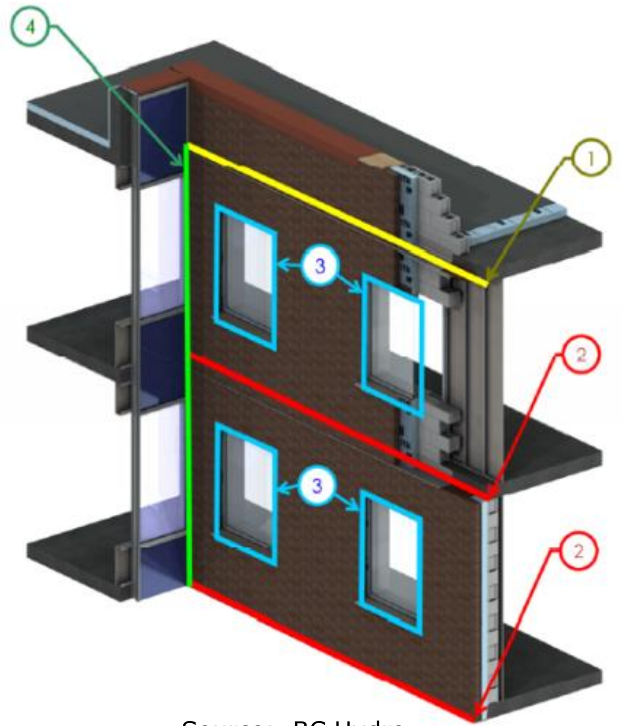
C107.2.2 Thermal envelope.

Inspections shall verify the correct type of insulation, *R*-values, location of insulation, *thermal bridge* mitigation, fenestration, *U*-factor, SHGC and VT, and that air leakage controls are installed, as required by the code, *approved* plans and specifications.

C202 Definitions

WALL, ABOVE-GRADE

A wall associated with the *building thermal envelope* that is more than 15 percent above grade and is on the exterior of the *building* or any wall that is associated with the *building thermal envelope* that is not on the exterior of the building. **This includes, but is not limited to, between-floor spandrels, peripheral edges of floors, roof knee walls, dormer walls, gable end walls, walls enclosing a mansard roof, mechanical equipment penetrations and skylight shafts.**



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

This revised definition clarifies that thermal bridges must be considered where provisions for "above-grade walls" apply (i.e., compliance with "clear field" assembly U-factors or R-values plus compliant detailing of various types of thermal bridges associated with wall construction as addressed in C402.7)

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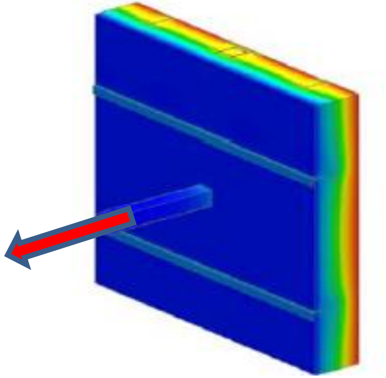
C202 Definitions

THERMAL BRIDGE. An element or interface of elements that has a higher thermal conductivity than the surrounding *building thermal envelope*, which creates a path of least resistance for heat transfer.

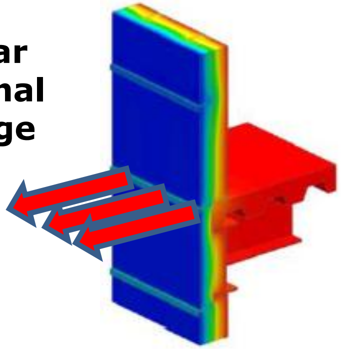
CHI-FACTOR (χ-FACTOR). The heat loss factor for a single thermal bridge characterized as a **point element** of a *building thermal envelope* (Btu/h x °F)[W/K].

PSI-FACTOR (ψ-FACTOR). The heat loss factor per unit length of a thermal bridge characterized as a **linear element** of a *building thermal envelope* (Btu/h × ft × °F)[W/(m × K)].

Point Thermal Bridge



Linear Thermal Bridge



Source: Morrison Hershfield LTD
ASHRAE RP 1365

C402.7 Thermal bridges in above-grade walls

C402.7 Thermal bridges in above-grade walls

Thermal bridges in above-grade walls shall comply with this section **or** an *approved* design.

Exceptions:

1. *Buildings* and structures located in Climate Zones 0 through 3.
   🡐 *No requirement in warmer climates where annual energy use impacts of thermal bridging are considered less significant and cost-effective (in general).*
2. Any *thermal bridge* with a material thermal conductivity not greater than 3.0 Btu/h-ft-°F.
   🡐 *EXCLUDES WOOD AND OTHER "LOW-CONDUCTIVITY" MATERIALS PENETRATING BTE (e.g., wood beam or joist penetration, but does not exempt wood framing in building assemblies)*
3. Blocking, coping, flashing, and other similar materials for attachment of roof coverings.
   🡐 *Provides practical allowance for necessary roofing system installation components without requiring each of these items to be assessed for energy code compliance.*
4. *Thermal bridges* accounted for in the *U*-factor or *C*-factor for a *building thermal envelope*.
   🡐 *AVOIDS DOUBLE-COUNTING (i.e., framing clear-field thermal bridges already included in U-factor/ R-value compliance)*

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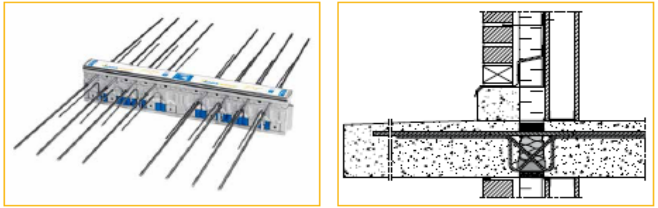
C402.7 Thermal bridges in above-grade walls

C402.7.1 Balconies and floor decks

Balconies and concrete floor decks shall not penetrate the *building thermal envelope*. Such assemblies shall be separately supported or shall be supported by structural attachments or elements that minimize thermal bridging through the *building thermal envelope*.

Exceptions: Balconies and concrete floor decks shall be permitted to penetrate the *building thermal envelope* where:

1. an area-weighted *U*-factor is used for *above-grade wall* compliance which that includes a *U*-factor of 0.8 Btu/h-F-ft^2 for the area of the *above-grade wall* penetrated by the concrete floor deck in accordance with Section C402.1.2.1.5;
2. an *approved* thermal break device with not less than R-10 insulation material installed in accordance with the manufacturer's instructions; or,
3. an *approved* design where the *above-grade wall* U-factor used for compliance accounts for all balcony and concrete floor deck *thermal bridges*.



Cantilevered Balcony Structural Thermal Break

Source: Google search

ABTG

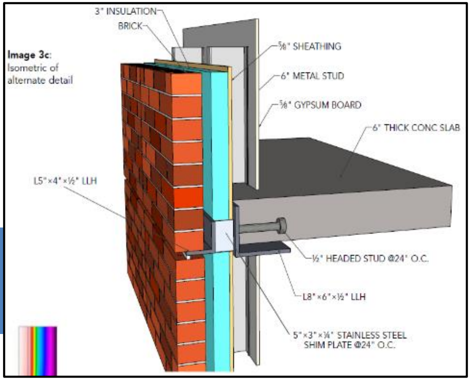
C402.7 Thermal bridges in above-grade walls

C402.7.2 Cladding supports

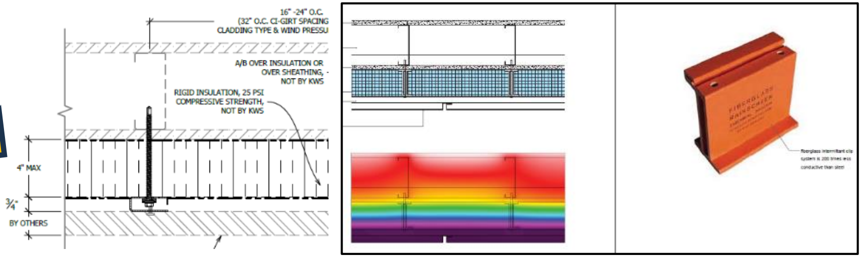
Linear elements supporting opaque cladding shall be off-set from the structure with attachments that allow the continuous insulation, where present, to pass behind the cladding support element except at the point of attachment.

Exceptions:

1. An *approved* design where the *above-grade wall U-factor* used for compliance accounts for the cladding support element *thermal bridge*. ← *Z-furring penetrating through exterior insulation is cavity insulation. It doesn't meet continuous insulation definition and must comply with its impact on wall U-factor addressed.*
2. Anchoring for *curtain wall* and window wall systems where *curtain wall* and window wall systems comply with C402.7.4.



OFFSET SHELF ANGLE (AISC/SEI article)



Low thermal conductivity furring/cladding/ledger supports

Sources: Payette/AIA report and product info from Google search

Examples: Offset shelf angle, offset furring with shear tab attachments, cladding/furring fastening through ci, etc.

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C402.7 Thermal bridges in above-grade walls

C402.7.3 Structural beams and columns

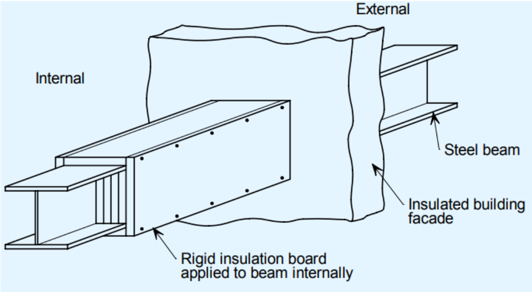


Figure 2.2 *Locally insulated beam*

Avoidance of Thermal Bridging in Steel Construction

steelconstruction.info/images/5/53/SCI_P380.pdf

Structural steel and concrete beams and columns that project through the *building thermal envelope* shall be covered with not less than R-5 insulation for not less than 2 feet (610 mm) beyond the interior or exterior surface of an insulation component within the *building thermal envelope*.

Exceptions:

1. Where an *approved* thermal break device is installed in accordance with the manufacturer's instructions.
2. An *approved* design where the *above-grade wall* U-factor used to demonstrate compliance accounts for the beam or column thermal bridge.

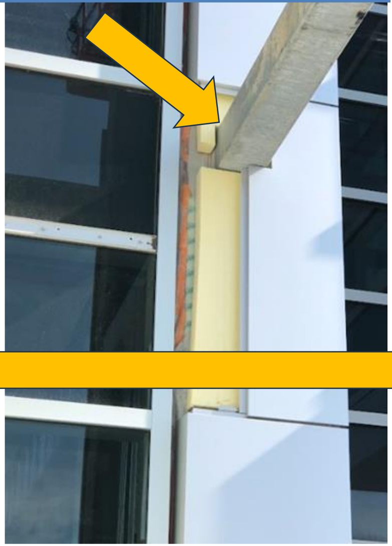
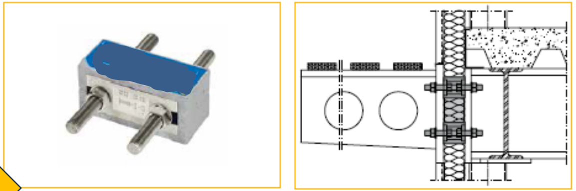


Photo by Shaunna Mozingo



Structural thermal block for steel beam projections through building envelope

Source: Google search

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C402.7 Thermal bridges in above-grade walls

C402.7.4 Vertical fenestration

Vertical *fenestration* intersections with above grade walls shall comply with one or more of the following:

1. **Where above-grade walls include continuous insulation**, the plane of the exterior glazing layer or, for metal frame *fenestration*, a non-metal thermal break in the frame shall be positioned within 2 inches (610 mm) of the interior or exterior surface of the continuous insulation.
2. **Where above-grade walls do not include continuous insulation**, the plane of the exterior glazing layer or, for metal frame *fenestration* , a non-metal thermal break in the frame shall be positioned within the thickness of the integral or *cavity insulation* .
3. **The surface of the rough opening, not covered by the fenestration frame**, shall be insulated with insulation of not less than R-3 material or covered with a wood buck that is not less than 1.5 inches (457 mm) thick.
4. For the intersection between **vertical fenestration and opaque spandrel in a shared framing system**, manufacturer's data for the spandrel *U*-factor shall account for *thermal bridges*.

Exceptions:

1. Where an *approved* design for the *above-grade wall U*-factor used for compliance accounts for *thermal bridges* at the intersection with the vertical fenestration.
2. Doors.

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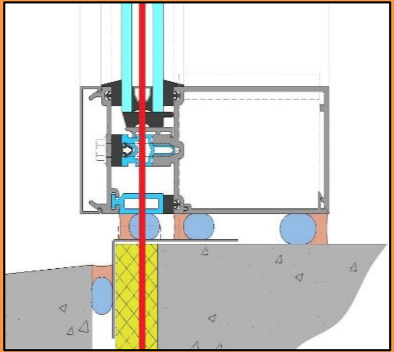
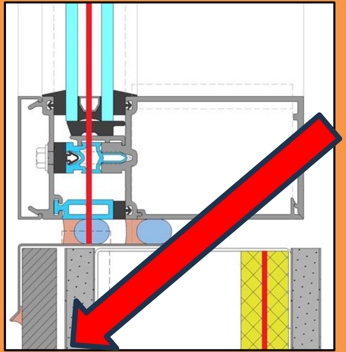
Mitigating Thermal Bridging at Fenestration-Wall Interface

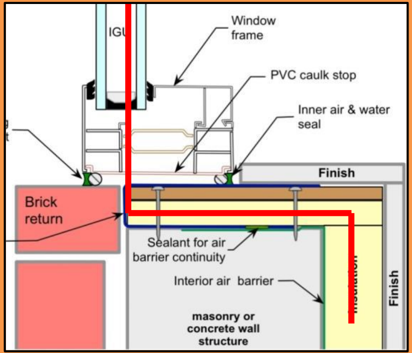
- **Simple approach:** align the glazing layer and frame thermal break within 2" of the wall insulation, *or*
- Wrap the exposed rough opening (RO) area between the window frame and the opaque wall insulation with R3 insulation or wood framing member.



Perfect Alignment



>2" misaligned



Wrap RO to align or butt WF

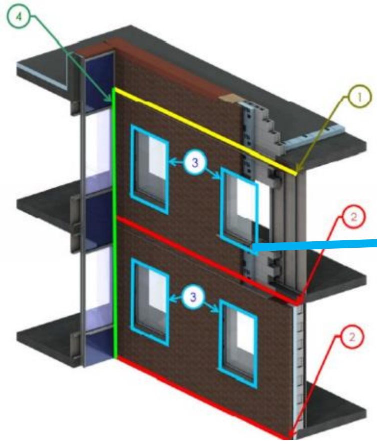
Image Sources: USACE report & Tom Culp

- *Or,* do detailed analysis accounting for the thermal bridging using a calculated psi-factor for the construction detail.

Thermal Bridging Impacts of Window-Wall Interface

Linear thermal bridge around perimeter of window opening

- Not accounted for in window component U-factor
- Not accounted for in wall clear-field assembly U-factor



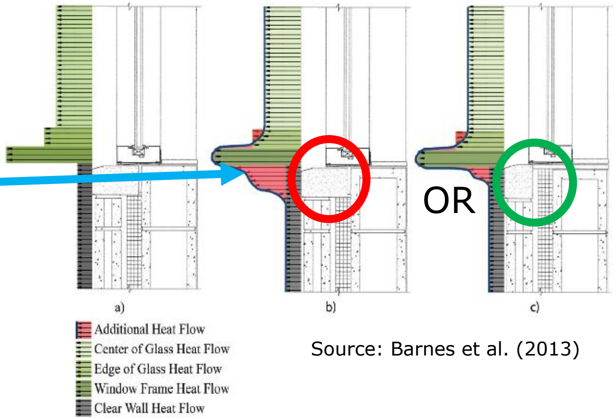
Source: Morrison-Hershfield (2020)

Wall-window interface ignored

Unmitigated: wall U-factor reduced by ~50%

OR

Mitigated: wall U-factor reduced by ~25%



Source: Barnes et al. (2013)

Comparison of "Poor" and "Efficient" Thermal Bridging Details at the Window-to-Wall Interface[1]

Thermal Bridge Condition		Clear-field Wall Thermal Performance (R13+7.5ci steel frame)[2]		Adjusted Wall Thermal Performance including Window-Wall Interface		Reduction in Wall Thermal Performance
Detailing Practice	Linear Thermal Transmittance (Psi-factor, Btu/hr-ft-F)	U-factor (Btu/hr-ft^2-F)	Effective R-value (1/U)	U-factor (Btu/hr-ft^2-F)	Effective R-value (1/U)	
"Poor"	0.3	0.064	R-15.6	0.134	R-7.5	52%
"Efficient"	0.1	0.064	R-15.6	0.088	R-11.4	27%

TABLE NOTES:
1. Table is based on a typical 3-story office building (168'x109') with 21,400 sf of gross above-grade wall area of cold-formed steel frame construction having R13 cavity insulation and R-7.5 continuous insulation on the exterior (i.e., R13+7.5ci wall per code as typical for moderate climate zones). The window-to-wall area ratio is assumed to be 33% for ribbon windows or 20% for punched window openings resulting in a total of about 3,200 ft of window perimeter interface with the wall assembly.
2. As a point of reference, a similar wall without the R7.5ci and having only R13 cavity insulation would have a U-factor of 0.125 Btu/hr-ft^2-F (effective R-value of 8) because in that case the steel frame thermal bridging in the clear-field of the assembly and at the fenestration perimeter would not be mitigated.

NOTE: Coordinate detailing at floor-wall and fenestration with NFPA 285 tested assemblies and approved engineering analysis details (applies to Type I-IV buildings, not Type V wood frame).

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C402.7 Thermal bridges in above-grade walls

C402.7.5 Parapets

Parapets shall comply with one or more of the following as applicable:

1. **Where continuous insulation is installed on the exterior side of the *above-grade wall* and the roof is insulated with insulation entirely above deck**, the continuous insulation shall extend up both sides of the parapet not less than 2 feet (610 mm) above the roof covering or to the top of the parapet, whichever is less. Parapets that are an integral part of a fire-resistance rated wall, and the exterior continuous insulation applied to the parapet, shall comply with the fire resistance ratings of the building code.
2. **Where continuous insulation is installed on the exterior side of the *above-grade wall* and the roof insulation is below the roof deck**, the continuous insulation shall extend up the exterior side of the parapet to not less than the height of the top surface of the *roof assembly* .
3. **Where continuous insulation is not installed on the exterior side of the *above-grade wall* and the roof is insulated with insulation entirely above deck**, the wall cavity or integral insulation shall extend into the parapet up to the exterior face of the roof insulation or equivalent R-value insulation shall be installed not less than 2 feet (610 mm) horizontally inward on the underside of the roof deck.
4. **Where continuous insulation is not installed on the exterior side of the *above-grade wall* and the roof insulation is below the roof deck**, the wall and roof insulation components shall be adjacent to each other at the roof-ceiling-wall intersection.
5. Where **a thermal break device with not less than R-10 insulation material** aligned with the *above-grade wall* and roof insulation is installed in accordance with the manufacturer's instructions.

Exception: An *approved* design where the *above-grade wall U*-factor used for compliance accounts for the parapet *thermal bridge*.

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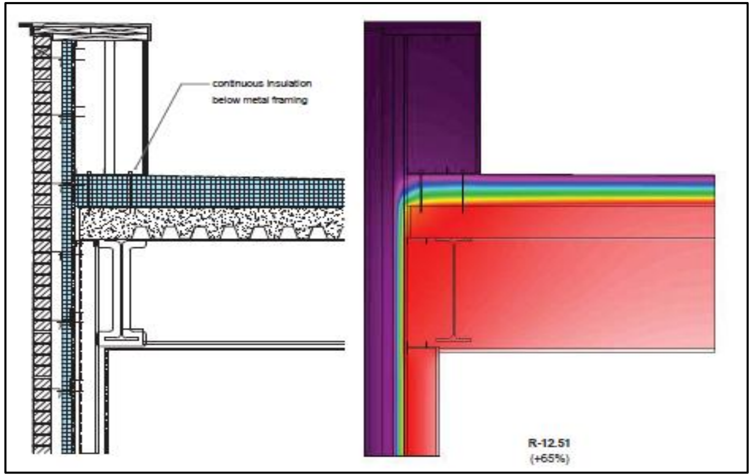
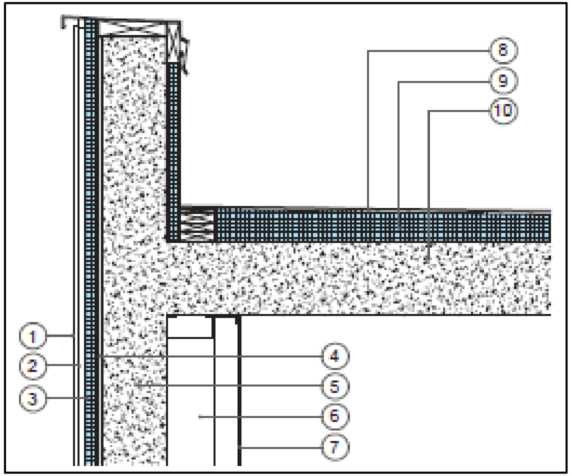
Mitigating Thermal Bridging at Parapets

Two example details…





INSULATED PARAPET DETAILS
(Payette/AIA report)

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C402.1.2.1.8 Mechanical equipment penetrations
(thermal bridge)

C402.1.2.1.8 Mechanical equipment penetrations.

Where the total area of through penetrations of mechanical equipment is greater than 1 percent of the opaque above grade wall area, such area shall be calculated as a separate wall assembly, in accordance with either Section C402.1.2.1.5 or Section C402.1.4 using a published and *approved* U-factor for that equipment or a default U-factor of 0.5.

C402.1.4 Component Performance Method

"Envelope Trade-off Method"

C402.1.4 Component performance method. Building thermal envelope values and fenestration areas determined in accordance with Equation 4-1 shall be an alternative to compliance with the U-, F-, psi- and chi-, and C-factors in Tables C402.1.2, C402.1.2.1.7, C402.1.4 and C402.5 and the maximum allowable fenestration areas in Section C402.5.1. Fenestration shall meet the applicable SHGC requirements of Section C402.5.3.

$$A_P + B_P + C_P + \mathbf{T_P} \leq A_T + B_T + C_T + \mathbf{T_T} - V_F - V_S$$

(Eq. 4-1)

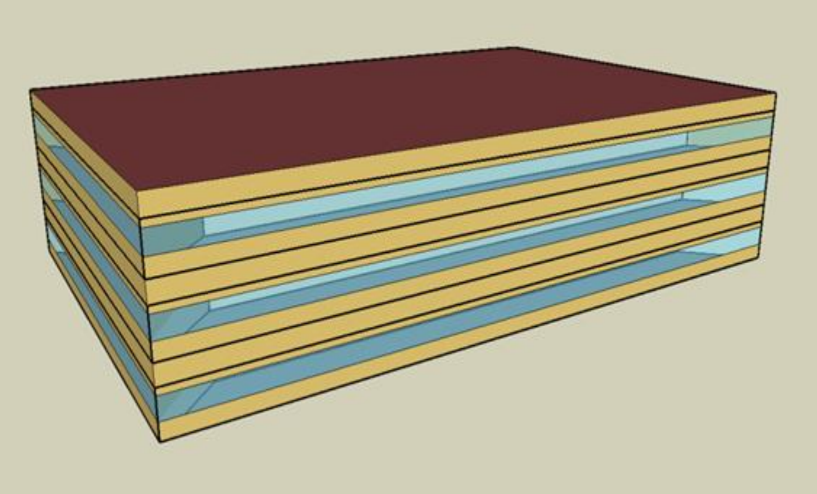
Subscripts: P = proposed, T = based on tabulated baseline values

- Provides a simplified building take-off and "math" approach to allow for trade-offs between BTE components
- Baseline performance is defined by maximum U-, F-, C-factor, requirements in Table C402.1.2 (opaque assemblies), C402.1.2.1.7 (spandrels), Psi-factor and Chi-factors in Table C402.1.4 (thermal bridges), and Table C402.5 (fenestration)
- Some assemblies or components increase, others must decrease in an offsetting fashion
- COMcheck provides an "equivalent" approach
  - pending release for 2024 IECC version with thermal bridging included

C402.1.4 Component Performance Method

Simple Office Building Example:

- Climate Zone 4 A/B
- 53,600 sqft
- 3 story
- 30% fenestration (C402.4.1 prescriptive limit % gross wall area)
- 164 ft x 109 ft
- 13 ft story height



NOTE: This example is truncated and only shows how to address thermal bridges in the code-compliance calculation per Eq.4-1

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C402.1.4 Component Performance Method

Use the values "Compliant with Section C402.7" as the baseline values for T_T calculation per Eq 4-1

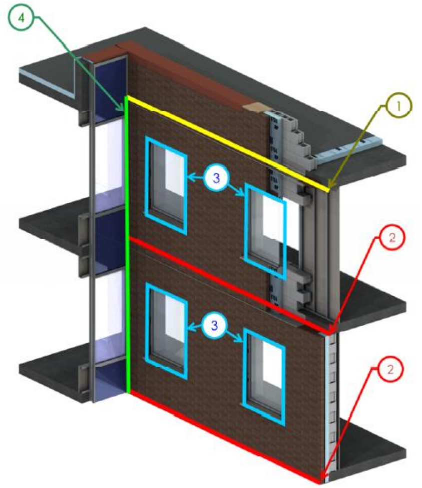
Use "Non-compliant" value only if doing no mitigation of a particular thermal bridge (you'll need to make-up for this elsewhere in the building thermal envelope)

TABLE C402.1.4 - PSI- and CHI-FACTORS TO DETERMINE THERMAL BRIDGES FOR THE COMPONENT PERFORMANCE METHOD

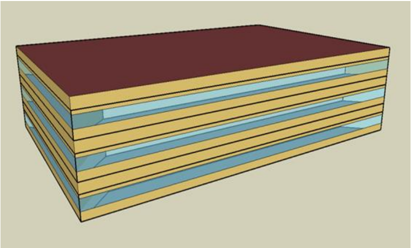
Thermal Bridge per Section C402.7	Thermal Bridge Compliant with Section C402.7		Thermal Bridge Non-Compliant with Section C402.7	
	psi-factor (Btu/h-ft-°F)	chi-factor (Btu/h-~~ft~~-°F)	psi-factor (Btu/h-ft-°F)	chi-factor (Btu/h-~~ft~~-°F)
C402.7.1 Balconies, slabs, and decks	0.2	n/a	0.5	n/a
C402.7.2 Cladding supports	0.2	n/a	0.3	n/a
C402.7.3 Structural beams and columns	n/a	1.0-carbon steel 0.3-concrete	n/a	2.0-carbon steel 1.0-concrete
C402.7.4 Vertical fenestration	0.15	n/a	0.3	n/a
C402.7.5 Parapets	0.2	n/a	0.4	n/a

For SI: W/m-K = 0.578 Btu/h-ft-°F; 1 W/K = 1.90 Btu/h-°F

C402.1.4 Component Performance Method



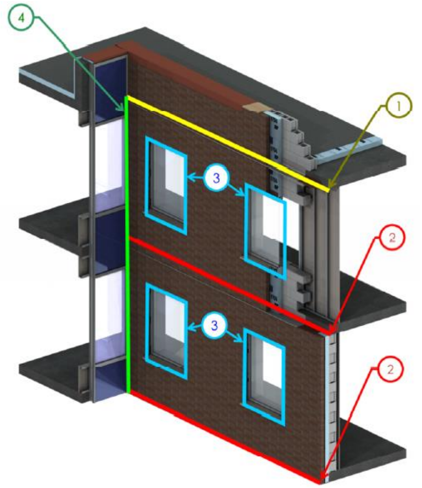
Source: BC Hydro BETB Guide / Morrison Hershfield LTD



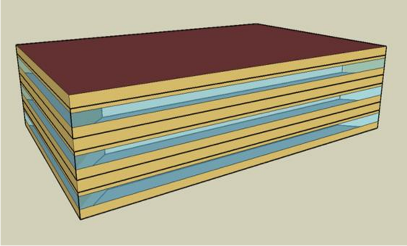
- Determine T_P and T_T for **thermal bridges**:
- **Floor deck/edges,** length = 2 intermediate floors x {2(164 ft) + 2(109 ft)} = 1,092 ft
  - Psi-factor table = 0.2 (offset shelf angle per C402.7.1)
  - Psi-factor proposed = 0.2 (same)
  - T_P_fldeck = 0.2(1,092) = **218**
  - T_T_fldeck = 0.2(1,092) = **218**

  NOTE: Slab-on-grade floor edge addressed by F-factor (same as a Psi-factor)
- **Parapet,** length = 2(164 ft) + 2(109 ft) = 546 ft
  - Psi-factor table = 0.2 (insulated both sides)
  - Psi-factor proposed = 0.4 (insulated one side)
  - T_P_para = 0.4(546) = **218**
  - T_T_para = 0.2(546) = **109**

C402.1.4 Component Performance Method



Source: BC Hydro BETB Guide / Morrison Hershfield LTD



- Determine T_P and T_T for thermal bridges:
- No structural beam/column penetrations
  - Chi-factor table x count = T_T_beam/col = 0
  - Chi-factor proposed x count = T_T_beam/col = 0
- Window-wall intersection length = 6 x {2(164 ft) + 2(109 ft)} = 3,276 ft
  - Psi-factor table = 0.15 (per detail options in C402.7.4)
  - Psi-factor proposed = 0.10 (improved detail by thermal analysis, testing, or approved source)
  - T_P_win-wall = 0.10(3,276) = **328**
  - T_T_win-wall = 0.15(3,276) = **491**

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C402.1.4 Component Performance Method

Now, sum and summarize all parameters:

- ΣA_P = 961+2005+129+572 = **3,667** — R13+7.5ci walls, U-0.32 fixed windows, U-0.77 entrance door, & R-30ci roof insulation entirely above deck
- ΣB_P = **197** — R-10ci, fully insulated slab (F-0.36)
- ΣC_P = 0 — No below-grade walls
- ΣT_P = 218+218+328 = **764** — Proposed thermal bridge details and associated Psi-/Chi- factors
- ΣA_T = 826+2131+109+572 = **3,638** — Baseline using tabulated U-factors
- ΣB_T = **284** — Baseline using tabulated F-factors
- ΣC_T = 0 — No below-grade walls using tabulated C-factors
- ΣT_T = 218+109+491 = **818** — Baseline using tabulated “compliant” thermal bridge Psi- / Chi-factors
- V_F = 0 — Windows < 30% gross wall area (no excess area)
- V_S = 0 — No skylights (thus, no excess skylight area)

SOLVE:

- $A_P + B_P + C_P + T_P \leq A_T + B_T + C_T + T_T - V_F - V_S$ (Eq. 4-1)
- Proposed: 3,667 + 197 + 0 + 764 = **4,628** **vs.** Baseline: 3,638 + 284 + 0 + 818 = **4,740**
  - **Proposed < Baseline → OK – compliant!**

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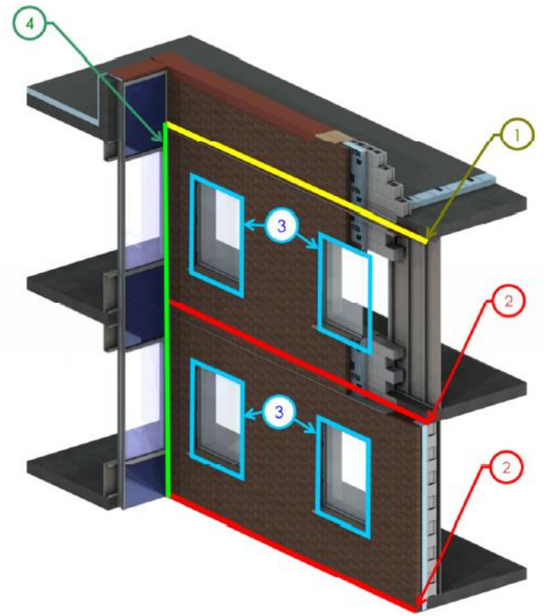
C407 Building Simulated Performance

TABLE C407.4.1(1) – SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT CHARACTERISTICS	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Walls, above-grade	Type: same as proposed	As proposed
	Gross area: same as proposed	As proposed
	U-factor: as specified in **Table C402.1.2**	As proposed
	Thermal bridges: Account for heat transfer consistent with compliant *psi*- and *chi*-factors from Table C402.1.4 for *thermal bridges* as identified in Section C402.7 that are present in the proposed design.	As proposed; *psi*- and *chi*-factors for proposed *thermal bridges* shall be determined in accordance with requirements in Section C402.1.4.

Adjustment of Clear-Field U-factor to Account for Point & Linear Thermal Bridges in 1-D Building Simulation Models



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

$$U_{adj} = \frac{\sum(\Psi \cdot L) + \sum(\chi \cdot n)}{A_{Total}} + U_o$$

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

Ψ_j = Psi-factor for linear thermal bridge type j

L_j = total length of linear thermal bridge type j

χ_k = Chi-factor for point thermal bridge type k

n_k = number of point thermal bridges of type k

A_{Total} = total surface area of the opaque envelope assembly to which the impact of thermal bridges are being attributed

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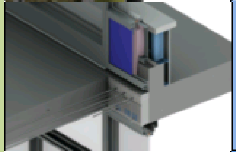
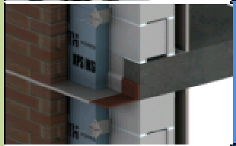
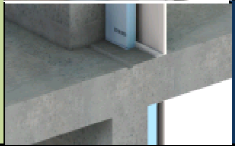
Example Design Data
(Psi-factors for floor edges)

Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

	Performance Category		Description and Examples	Linear Transmittance	
				Btu / hr ft F	W / m K
FLOOR AND BALCONY SLABS		**Efficient**	**Fully insulated with only small conductive bypasses** Examples: exterior insulated wall and floor slab.	0.12	0.2
		Improved	**Thermally broken and intermittent structural connections** Examples: structural thermal breaks, stand-off shelf angles.	0.20	0.35
		Regular	**Under-insulated and continuous structural connections** Examples: partial insulated floor (i.e. firestop), shelf angles attached directly to the floor slab.	0.29	0.5
		Poor	**Un-insulated and major conductive bypasses** Examples: un-insulated balconies and exposed floor slabs.	0.58	1.0

Source: BC Hydro BETB Guide / Morrison Hershfield LTD

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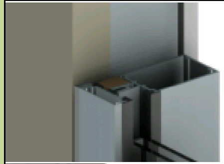
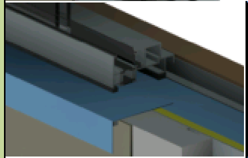
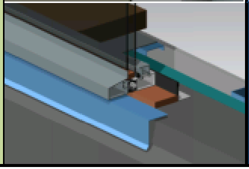
Example Design Data

(Psi-factors for fenestration-wall interface)

Table 1.4: Performance Categories and Default Transmittances for Glazing Transitions

GLAZING TRANSITIONS	Performance Category		Description and Examples	Linear Transmittance	
				Btu / hr ft F	W / m K
		**Efficient**	**Well aligned glazing without conductive bypasses** Examples: wall insulation is aligned with the glazing thermal break. Flashing does not bypass the thermal break.	0.12	0.2
		Regular	**Misaligned glazing and minor conductive bypasses** Examples: wall insulation is not continuous to thermal break and framing bypasses the thermal insulation at glazing interface.	0.20	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).	0.29	0.5

Source: BC Hydro BETB Guide / Morrison Hershfield LTD

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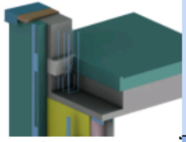
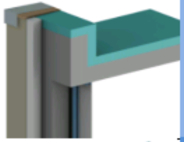
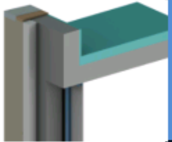
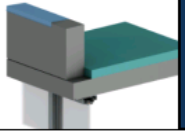
Example Design Data

(Psi-factors for parapet roof-wall intersection)

Table 1.5: Performance Categories and Default Transmittances for Parapets

	Performance Category		Description and Examples	Linear Transmittance Btu / hr ft F	Linear Transmittance W / m K
PARAPETS		**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

Conclusions

Prior to 2024 IECC (and ASHRAE 90.1-2022), thermal bridging was generally 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 continuous insulation with good details to mitigate thermal bridges can significantly improve building thermal envelope performance.

The 2024 IECC (and ASHRAE 90.1-2022) provide new thermal bridging provisions with practical requirements, prescriptive details, and alternative compliance options.

Several sources of data and design guidance are available to support code-compliance and appropriate mitigation of thermal bridges (see Resources & Bibliography).

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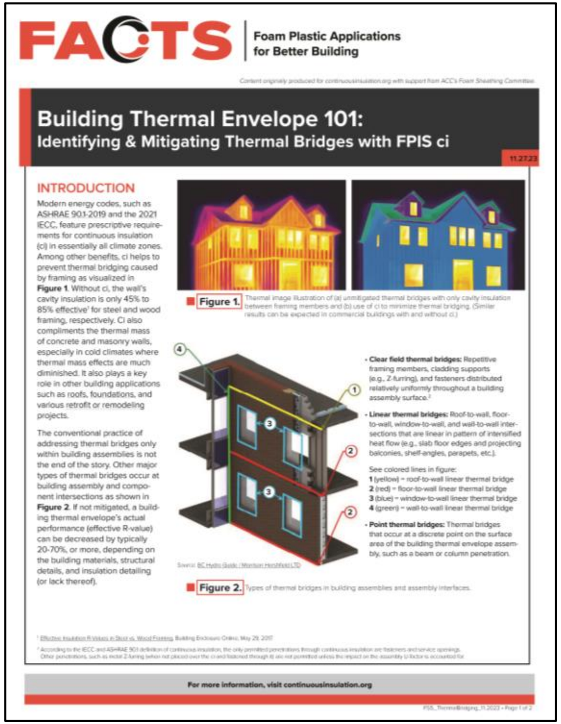
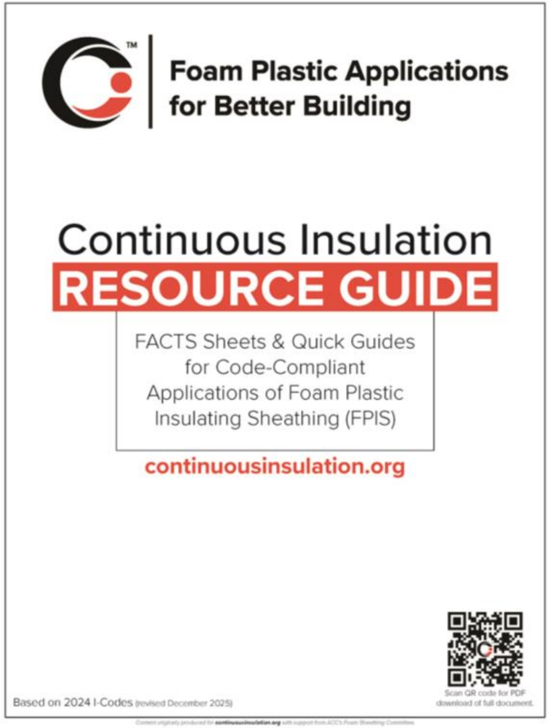
Ci Resources (continuousinsulation.org)





Questions? Submit inquiries at continuousinsulation.org/contact.

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