Thermal Bridging:
Small Details with a Large Impact & Getting Ready for New Codes

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Foam Plastic Applications for Better Building

Outline

- Types of Thermal Bridges & Implications
- Energy Code Requirements for Thermal Bridges
- Design and Mitigation Concepts
- Examples of Thermal Bridge Mitigation Strategies & Details
- Calculation Methods and Design Data
- Design Example
- Conclusions
- Bibliography (design resources)

Learning Objectives

1. Learn the types of thermal bridges and their impacts
2. Learn new energy code requirements for thermal bridges
3. Learn how to account for thermal bridges prescriptively and by design
4. Learn how to mitigate thermal bridges using improved details with continuous insulation

Course Description

- The International Energy Conservation Code (IECC) will become a new consensus standard available for adoption in 2024. It and ASHRAE 90.1-2022 contain a number of significant changes affecting building enclosure design, especially for thermal bridging. This presentation reviews the new thermal bridging requirements in the IECC (similar for ASHRAE 90.1) and focuses on detailing and design requirements for mitigating thermal bridging in building enclosures. The code text as well as illustrated solutions will be presented to provide a practical understanding for code compliance.

What is a thermal bridge?

A thermal bridge is not a burning bridge, although both have something to do with an increased rate of heat transfer or energy loss.

Burning bridge releasing the embodied (stored) energy.
Source: Steve Dadds; as published in azfamily.com by 3TV/CBS 5, posted Aug. 17, 2015.

Thermal imaging illustration of unmitigated framing thermal bridges releasing heating energy (no continuous insulation).

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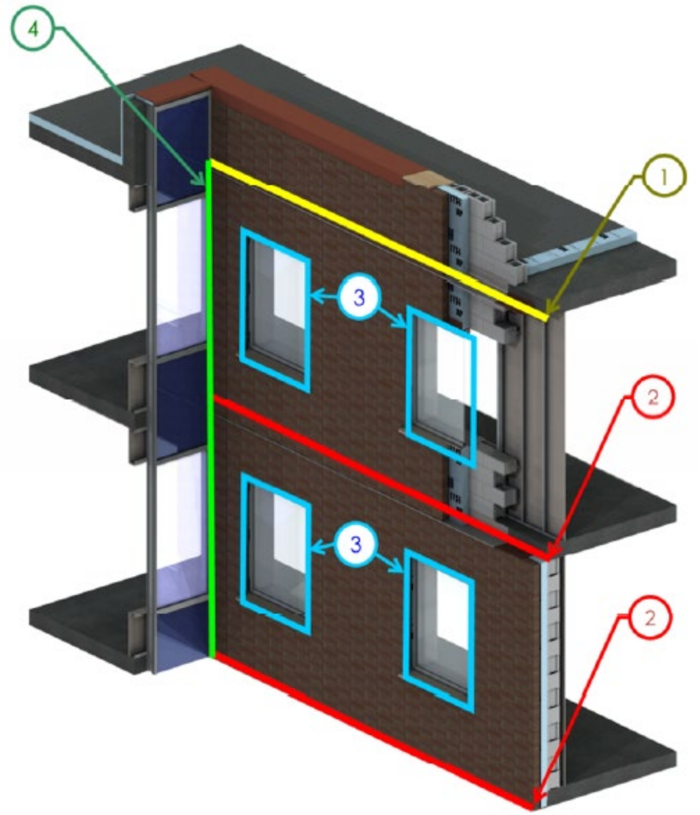
Types of Thermal Bridges

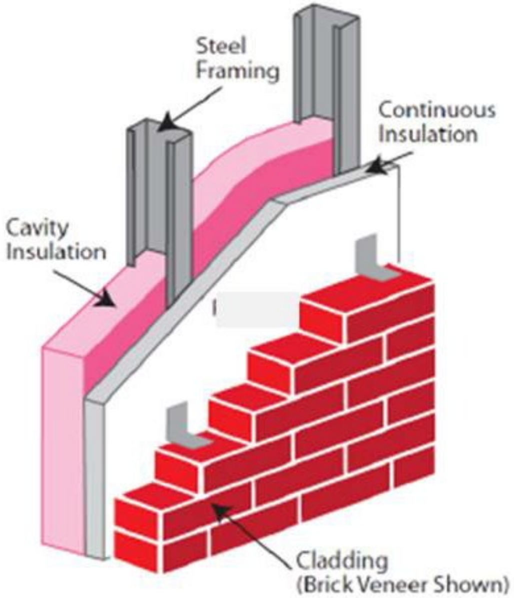
- Clear-field thermal bridge
- Linear thermal bridge
- Point thermal bridge

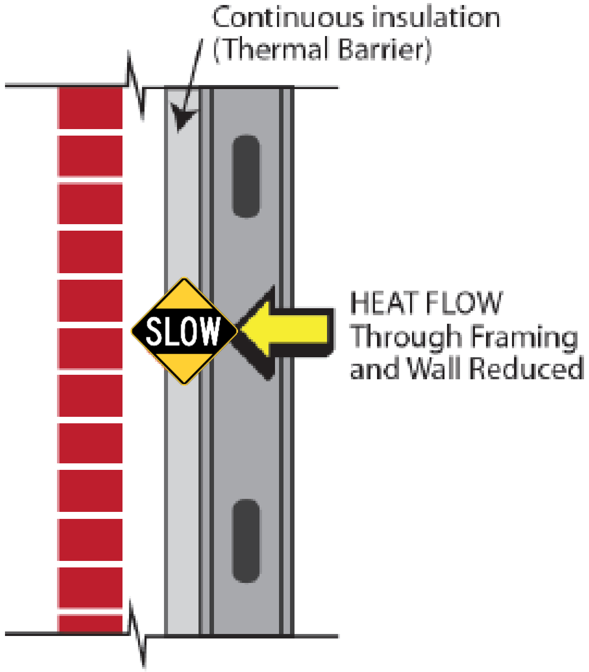


Source: BC Hydro BETB Guide / Morrison Hershfield LTD

Clear-Field Thermal Bridge

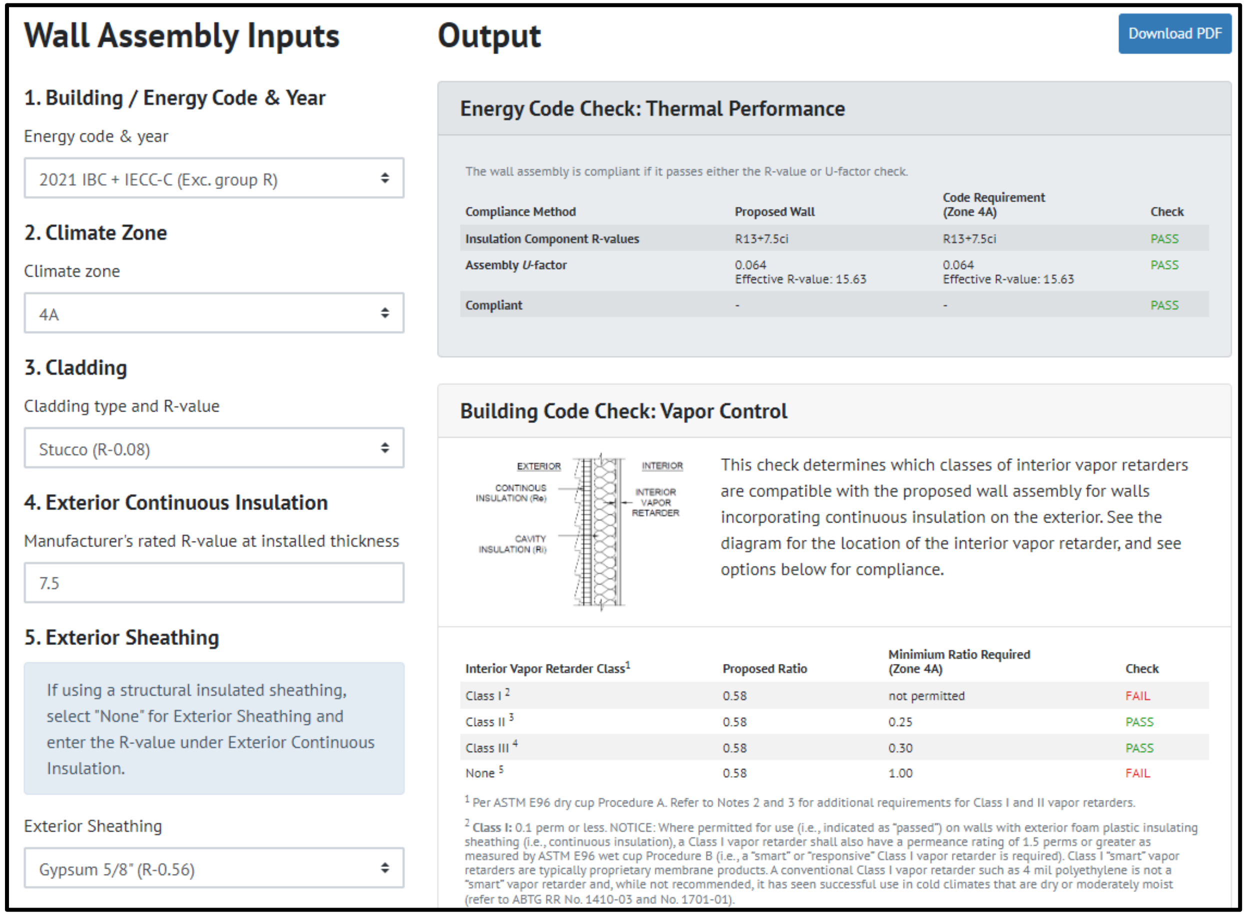
- Clear-Field Thermal Bridge
  - Thermal pathways inherent to a building assembly and its surface area
  - Generally accounted for in U-factor calculations, R-value prescriptions, and assembly thermal test methods for energy code compliance
    - Examples: Wood and steel studs and plates (framing), webs 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 (with no added framing for wall openings)
      - More than 50% loss in insulation R-value
    - For example, cavity insulation in wood framing is about 83% effective
      - Wall with R-21 cavity insulation has an effective R-17.2 to R-17.5 (including plates and headers and jamb studs for wall openings)
      - More than 15% loss in insulation R-value





Clear-Field Thermal Bridge - Resources

- Design Tool: Steel Wall & Wood Wall Calculators
  - Performs U-factor and water vapor control design checks for coordinated energy code and building code compliance
- Free on-line tool available!
  - https://www.continuousinsulation.org/calculators
- YouTube tutorial also provided. Simple!



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).

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.

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

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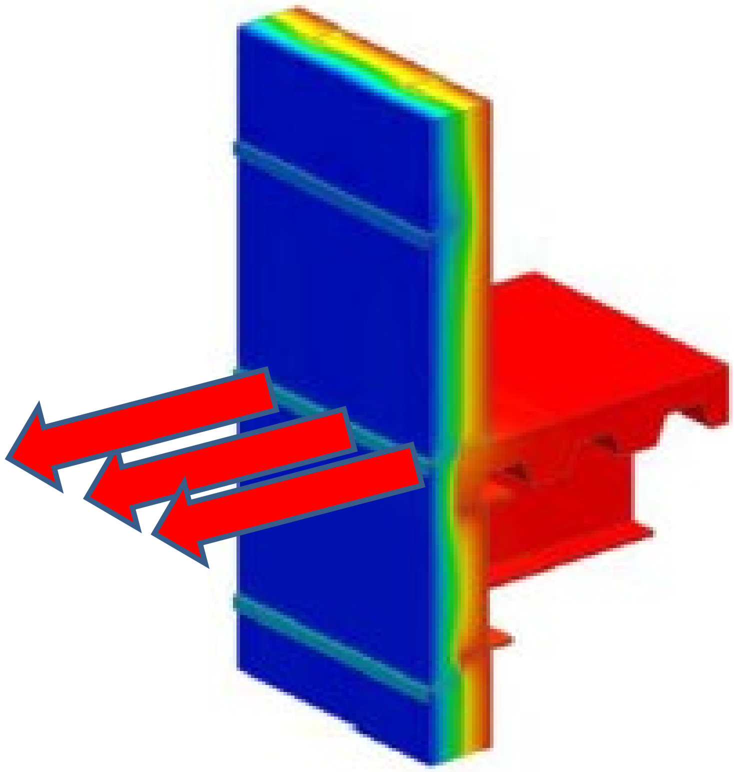
Linear Thermal Bridge

- **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-°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 used for purposes of "compliance" with 90.1 or IECC building thermal envelope assembly requirements:
    - — Exception:
      1) F-factors for insulation of slab-on-grade foundation edges for insulation configurations consistent with the F-factor selected.



Linear Thermal Transmittance

Source: Morrison Hershfield LTD / ASHRAE RP 1365

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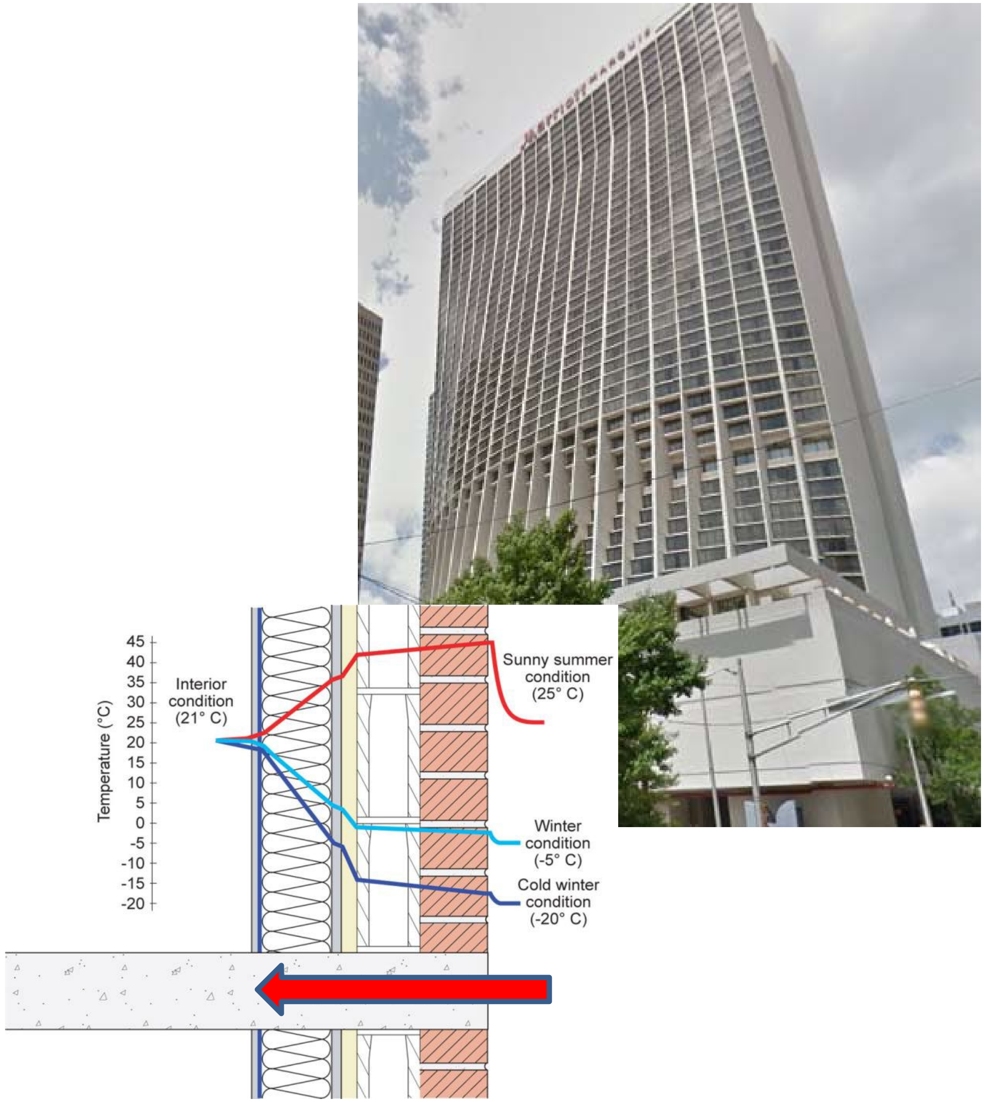
Linear Thermal Bridge

- **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!
  - And they are not accounted for in the energy codes' assembly U-factors and R-values!



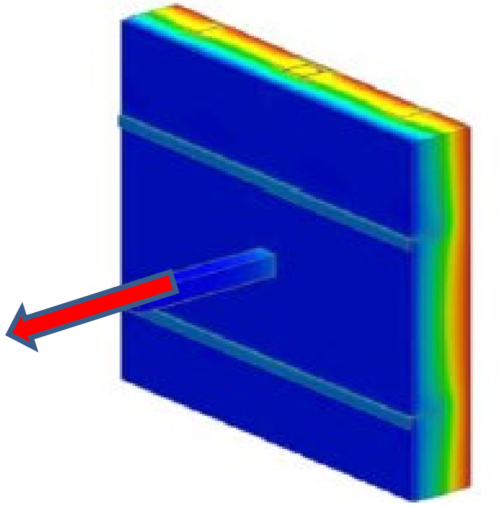
Source: USACE report

Point Thermal Bridge

- 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
  - Generally not accounted for in U.S. energy codes and standards, but not as severe as linear thermal bridges in "normal" quantities.
  - **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
    - Code definition for continuous insulation permits fastener penetrations (point thermal bridges) but not linear thermal brides (e.g., framing or Z-furring through ci layer)
  - **Impact:** Assembly U-factor increased 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, 3-D geometry, etc.



Point Thermal Transmittance

Source: Morrison Hershfield LTD / ASHRAE RP 1365

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What are the implications of unaccounted thermal bridges?

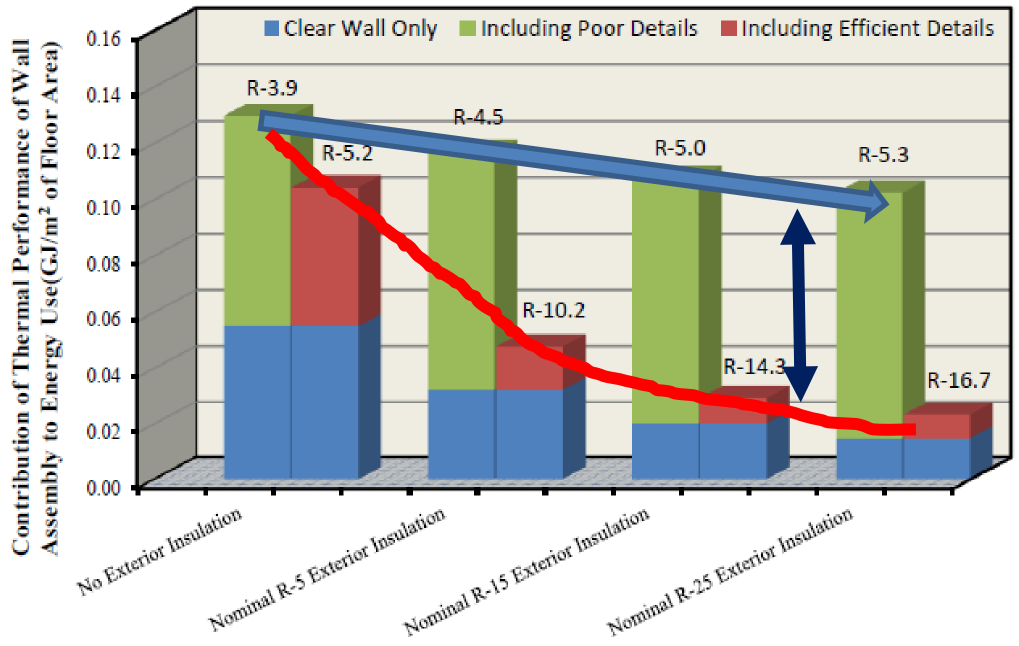

Figure 4.7: Additional building energy use based on thermal performance of the building wall assembly for varying amounts of nominal exterior insulation for a mid-rise MURB in Edmonton (overall assembly thermal resistance in $ft^2 \cdot °F \cdot h/Btu$ also given)

Source: Morrison Hershfield Ltd

- 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)
- Use of continuous insulation with good thermal bridge detailing is key to meeting intended performance.

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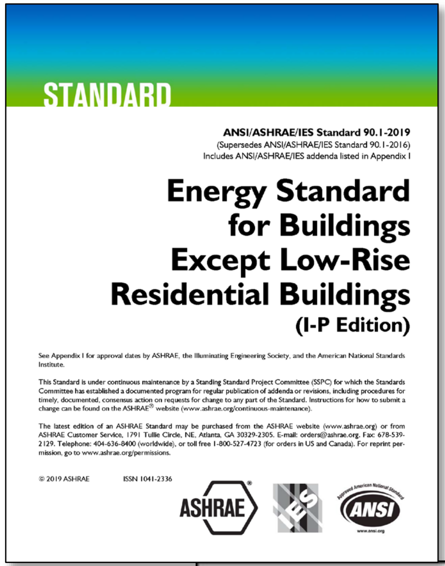
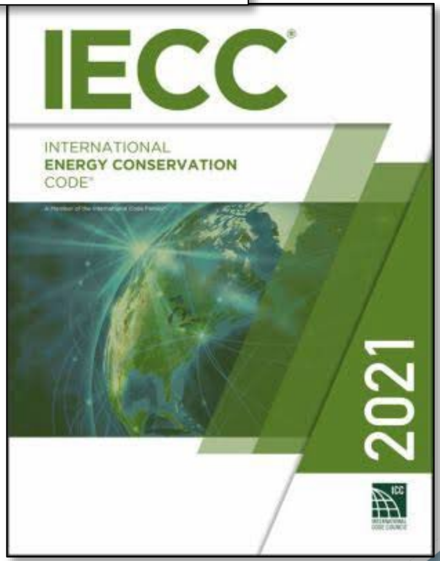
What have past codes required?

- Repetitive framing thermal bridges (studs, tracks, headers, joists, rafters, 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 been accounted for or clearly addressed in past codes.
  - ASHRAE 90.1-2019 and earlier - Performance path has required them to be considered as "uninsulated assemblies", but this is inaccurate and often not enforced or applied.
  - IECC 2018 and earlier – thermal bridges beyond assembly U-factors are all ignored.
  - IECC 2021 - "above-grade wall" definition revised to include thermal bridges at assembly and component intersections with wall (but not enabled by requirements and data in the code).
  - Prescriptive R-value path in the IECC and ASHRAE 90.1 (baseline for the performance path) was built on the assumption of no unaccounted thermal bridges.





What will the newer codes require?

- **2024 IECC** – New provisions added to account for thermal bridges at assembly and component intersections.
  - Prescriptive (R-value path) minimum requirements for insulation/structure details.
  - Thermal bridging included in component performance trade-off (i.e., prescriptive UA trade-off method)
  - Requirements for reference design and proposed design in performance modeling (simulation) path.
- **ASHRAE 90.1-2022** – New thermal bridging provisions also added
  - Similar to IECC provisions (similar sources considered by both)
  - Few more options but different approach (i.e., more complicated prescriptive requirements)
- Both focus only on the “big” thermal bridges and either are silent on or provide allowances for other less significant thermal bridges.
- Does not achieve “ideal” mitigation of thermal bridges (but significantly improves on current practice).
- Both will allow alternative solutions with at least equivalent performance (e.g., proprietary thermal bridge mitigation devices).

2024 IECC 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)].

2024 IECC 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. <u>Thermal bridges as identified in Section C402.6</u>.

  Etc.

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2024 IECC – Prescriptive Thermal Bridging Rules

- **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.
  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
  3. Blocking, coping, flashing, and other similar materials for attachment of roof coverings.
  4. *Thermal bridges* accounted for in the *U*-factor or *C*-factor for a *building thermal envelope*. ← AVOIDS DOUBLE-COUNTING (I.E., FRAMING)

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2024 IECC - Prescriptive

- **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 of with not less than R-10 insulation material is 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*.

2024 IECC - Prescriptive

- **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*.

  2. Anchoring for *curtain wall* and window wall systems where *curtain wall* and window wall systems comply with C402.7.4.

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

2024 IECC - Prescriptive

- **C402.7.3 Structural beams and columns** 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.

2024 IECC - Prescriptive

- **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.

2024 IECC - Prescriptive

- **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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2024 IECC - Prescriptive

- **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.

2024 IECC – Prescriptive (UA trade-off method)

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

2024 IECC – Performance (Simulation) Path

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.
	Solar ~~absorptance: 0.75~~reflectance: 0.25	As proposed
	Emittance: 0.90	As proposed

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
    - Steel framing calculation methods (and the new AISI S250 standard) excludes impact of additional framing for wall openings; correction may be necessary.
  - 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 where required by code.
  - Also, see 2024 IECC (residential) new APPENDIX RF for U-factor and F-factor data
    - Also includes "effective" U-factors for below grade walls which must be used in prescriptive UA trade-off approaches.

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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 metal or wood furring over (not through) continuous insulation layer (RESOURCE: https://www.continuousinsulation.org/cladding-connections)
  - 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

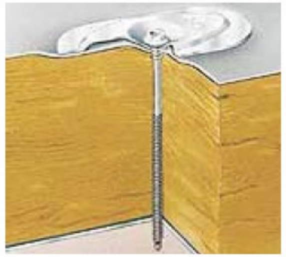

Fig1: Solid metal fastening solution

Fig. 2: Version with plastic sleeve and shorter fastener

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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 (carbon fiber, fiberglass, brick ties with thermal-break joints, etc.)

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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

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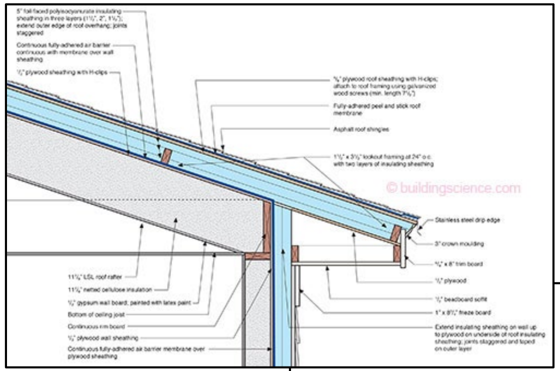
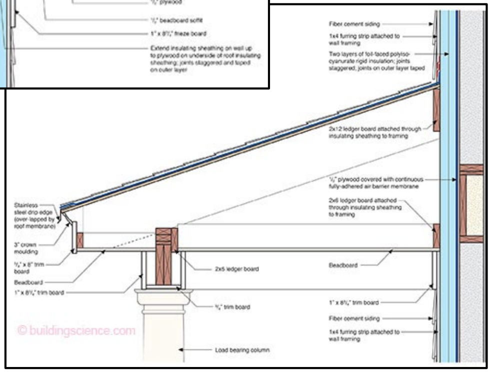
Examples of Mitigated Linear Thermal Bridges
(Balconies)

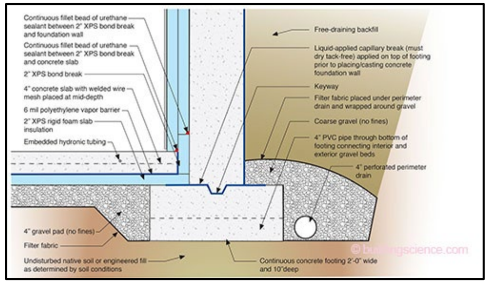
Photos courtesy of John Hogan

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

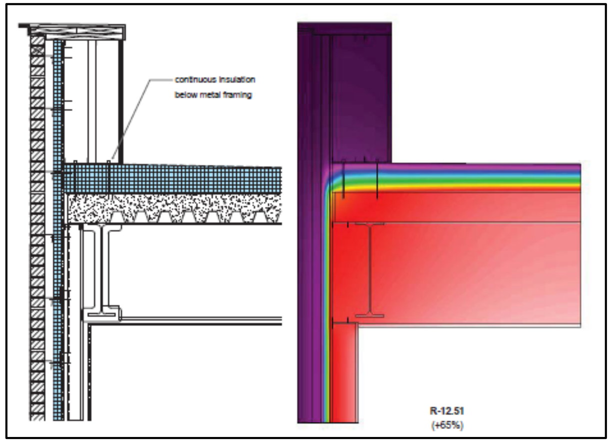
More Examples of Mitigated Linear Thermal Bridges
(non-exhaustive “commodity” details)

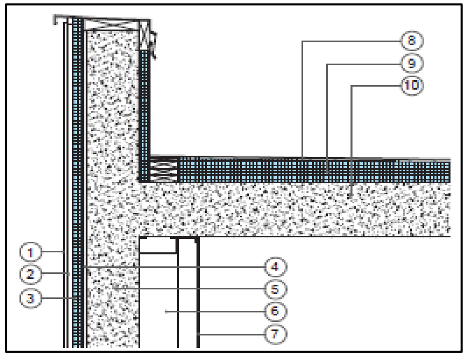




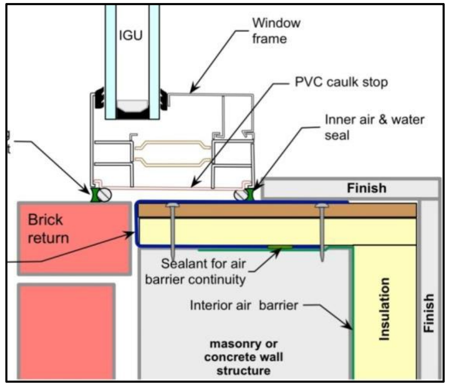


Example Details from BSI-081: Zeroing In (J. Lstiburek, Building Science Corp) as used on NIST NZERTF Project

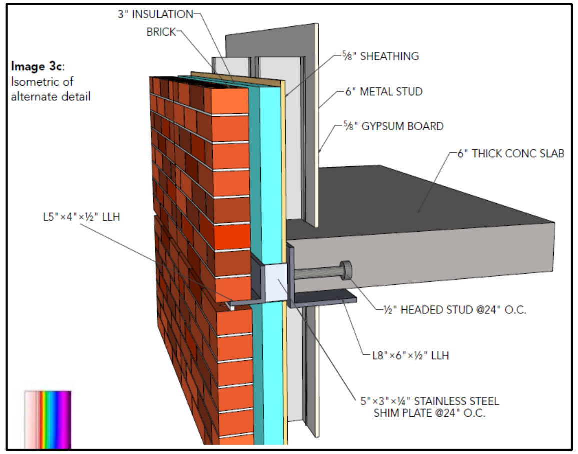




INSULATED PARAPET DETAILS (Payette/AIA report)



INSULATED WINDOW ROUGH OPENING DETAIL (USACE report)

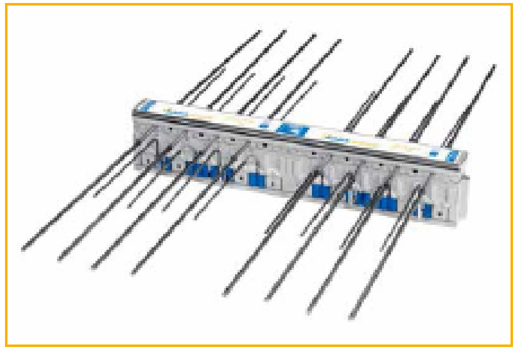


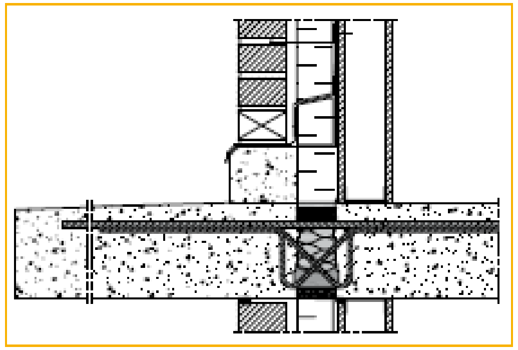
OFFSET SHELF ANGLE (AISC/SEI article)

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).

Examples of Proprietary Thermal Bridging Devices

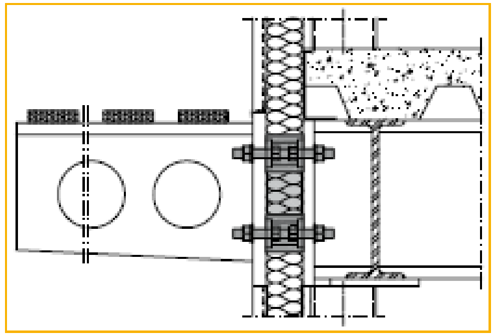
(non-exhaustive "google" search)





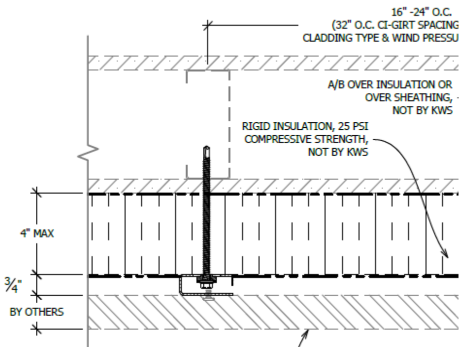
Cantilevered Balcony Structural Thermal Break

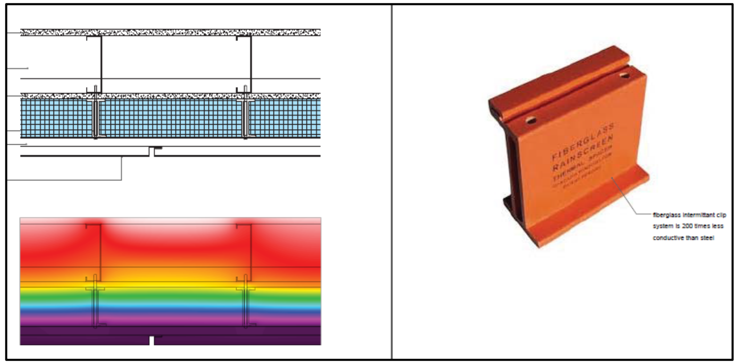
Source: Google search



Structural thermal block for steel beam projections through building envelope

Source: Google search

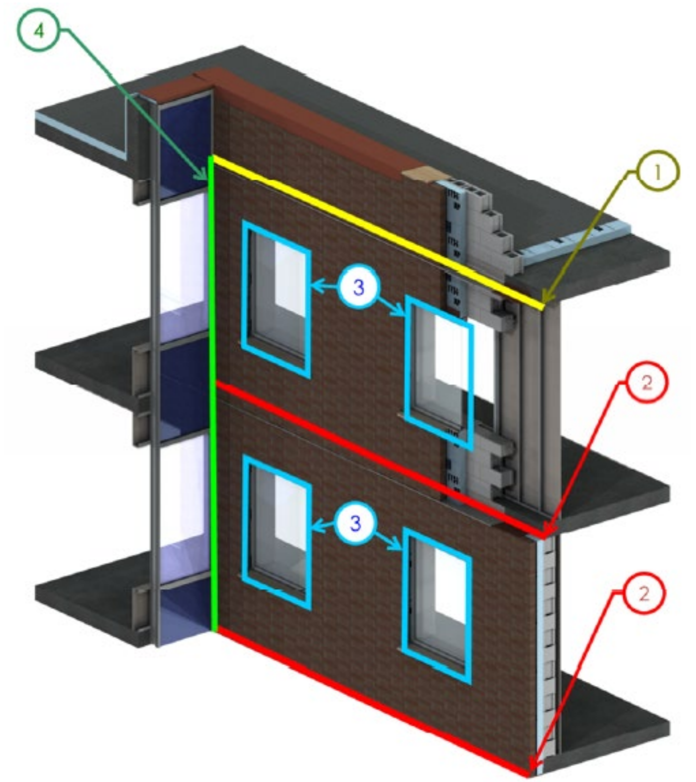




Low thermal conductivity furring/cladding/ledger supports

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

Calculations to Account for Point & Linear Thermal Bridges



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

$$Q = [\ \Sigma\ (U_i \cdot A_i) + \Sigma\ (\psi_j \cdot L_j) + \Sigma\ (\chi_k . n_k)\ ] \times \Delta T$$

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

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

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

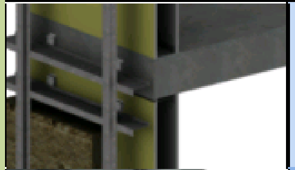
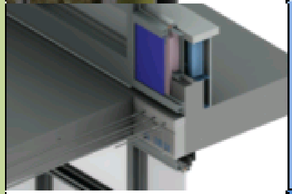
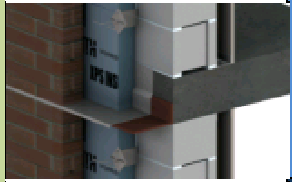
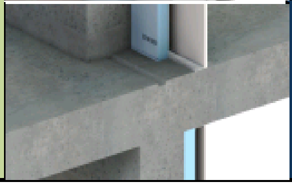
where:

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

Example Design Data (Psi-factors for floor edges)

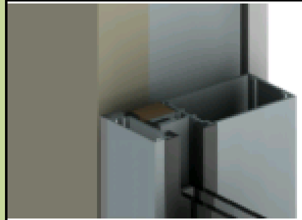
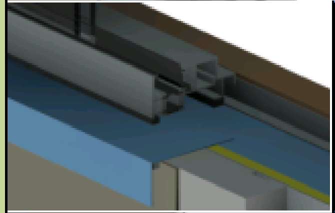
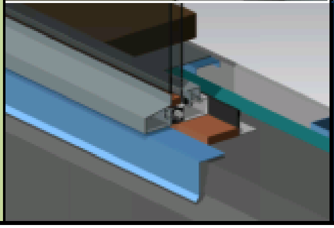
Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

	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

Example Design Data
(Psi-factors for fenestration-wall interface)

Table 1.4: Performance Categories and Default Transmittances for Glazing Transitions

	Performance Category		Description and Examples	Linear Transmittance	
				Btu / hr ft F	W / m K
GLAZING TRANSITIONS		**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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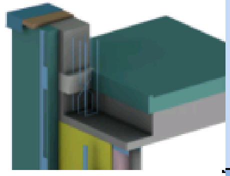
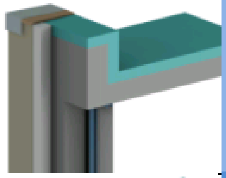
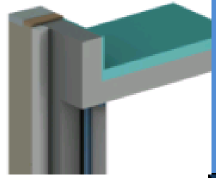
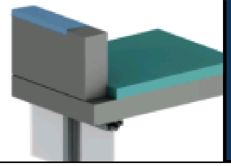
Example Design Data
(Psi-factors for parapet roof-wall intersection)

Table 1.5: Performance Categories and Default Transmittances for Parapets

	Performance Category		Description and Examples	Linear Transmittance	
				Btu / hr ft F	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

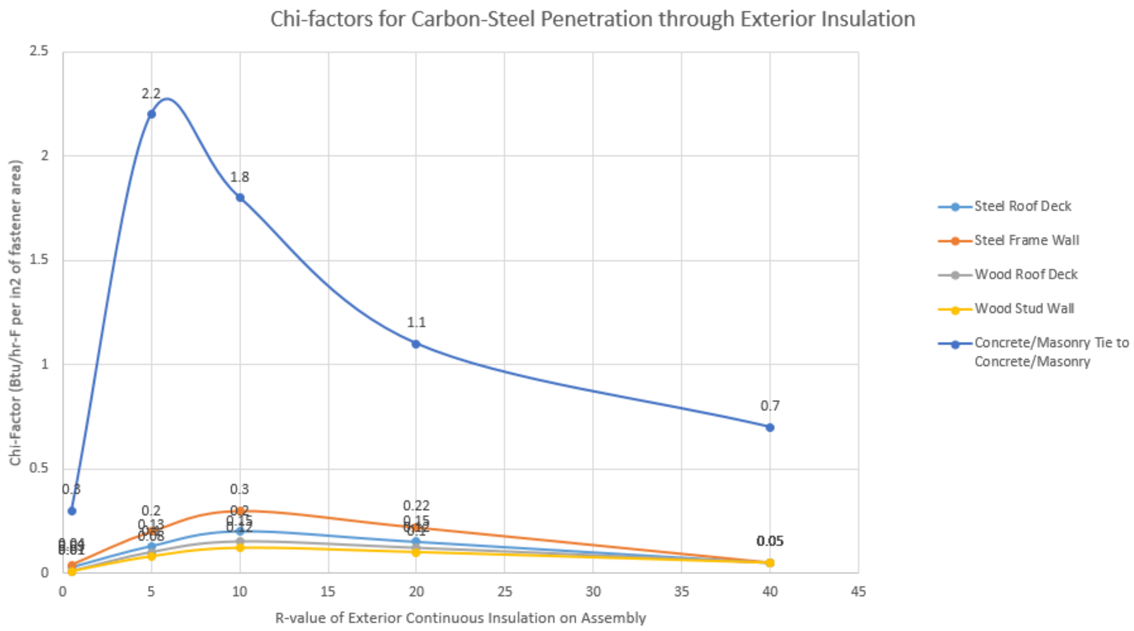
Source: BC Hydro BETB Guide / Morrison Hershfield LTD

Example Design Data
(Chi-factors for metal/fastener penetrations)

TABLE 2
Representative Point Thermal Bridge Thermal Transmittance Values
(Chi-Factors, Btu/hr-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]

R-value of insulation component layer penetrated by metal element	Steel Framing		Wood Framing		Concrete/Masonry
	Roof (Metal Deck)	Wall (Steel Studs)	Roof (WSP Deck)	Wall (Wood Studs)	Walls or Roof Deck
	Carbon steel fastener/connector through above deck insulation to steel deck	Carbon steel fastener/connector through exterior insulation or sheathing to studs	Carbon steel fastener/connector through above-deck roof insulation to wood sheathing	Carbon steel fastener/connector through exterior insulation or sheathing to studs	Carbon steel fastener/tie penetrating continuous insulation and embedded in two outer layers of concrete/masonry
R-0.5 (e.g., non-insulating sheathing)	0.03[2]	0.04 (Mayer et al., 2014)	0.01[2]	0.01 (Christensen, 2010)	0.3[2]
R-5ci	0.13[2]	0.2[2]	0.1 (Burch et al., 1987)	0.08 (Christensen, 2010)	2.2 (ASHRAE 90.1)
R-10ci	0.2 (Wieland, 2006; Burch et al., 1987; ISO 6946 Eq. D.5)	0.3[3] (Mayer et al., 2014; Posey and Dalgliesh, 2005; and unpublished data)	0.15 (Burch et al., 1987; ISO 6946 Eq. D.5)	0.12 (Christensen, 2010; Posey & Dalgliesh, 2005)	1.8 (ASHRAE 90.1) or 0.6 stainless steel (Van Geem & Shirley, 1987)
R-40ci	0.05 (Weiland, 2006; ISO 6946 Eq. D.5)	0.05[2]	0.05[2]	0.05[2]	0.7 (ASHRAE 90.1)

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 columns 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 hinged connections that disrupt the heat flow path), the normalized chi-factor may be as low as ~0.1 Btu/hr-F per in^2 of tie cross-section area penetrating insulation (pers. comm. Patrick Roppel, Morrison-Hershfield, Jan. 15, 2016).



Source: ABTG RR No. 1510-03
Available at: https://www.continuousinsulation.org/thermal-bridging-prevention

Clear-field U-factor Analysis –

CFS steel frame wall with and without ci

	2015 IECC Climate Zones & Insulation (C402.1.4.1 Calculation Method)						
	Zone 1, 2	Zone 2-8		Zone 7res	Zone 8res	n/a	n/a
Wall Component	4"C-stud	4" C-stud	6" C-stud	4" C-stud	4" C-stud	6" C-stud	6" C-stud
Outside air film	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Siding	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Continuous insulation	**5**	**10**	**8.5**	**15.6**	**17.5**	**0**	**3.8**
Gypsum Sheathing 1/2"	0.45	0.45	0.45	0.45	0.45	0.45	0.45
subtotal exterior R-value:	6.07	11.07	9.57	16.67	18.57	1.07	4.87
Cavity Insulation	**13**	**13**	**19**	**13**	**13**	**19**	**21**
Cavity Correction Factor	0.46	0.46	0.37	0.46	0.46	0.37	0.35
Eff. Cavity insulation	**5.98**	**5.98**	**7.03**	**5.98**	**5.98**	**7.03**	**7.35**
1/2 drywall (int. R-value)	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Inside air film	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Nom. U-factor (no fasteners)	**0.075**	**0.054**	**0.056**	**0.042**	**0.039**	**0.106**	**0.074**
Effective R (no fasteners)	**13.4**	**18.4**	**17.9**	**24.0**	**25.9**	**9.4**	**13.5**
U-factor increase due to fastener heat loss (delta-U = Chi x FAR x 144in^2/ft^2):							
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:

FAR = fastener cross-section area (in^2) per in^2 of wall area x 100%

0.020% Siding fastener area ratio (see below)
0.000% 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 implicity to the cavity correction factors

0.000% Interior gypsum board fastener ratio (see note above and below)

<u>Typical steel frame wall framing surface layer connections:</u>

gysum int. = 12"x16" #6 screws, 0.016in^2 = 0.008%
Gypsum ext. = 62 #8 screws per 32sqft, 0.021in^2 = 0.028%
CI board = 42 #8 screws per 32sqft, 0.0.021in^2 = 0.019%
6" Lap Siding = 1screw,0.016in^2, per 80in^2 = 0.02%
Brick Ties = 2"x0.033" tie at 16"x24", 2.67ft^2 = 0.017%

Source: ABTG RR No. 1510-03

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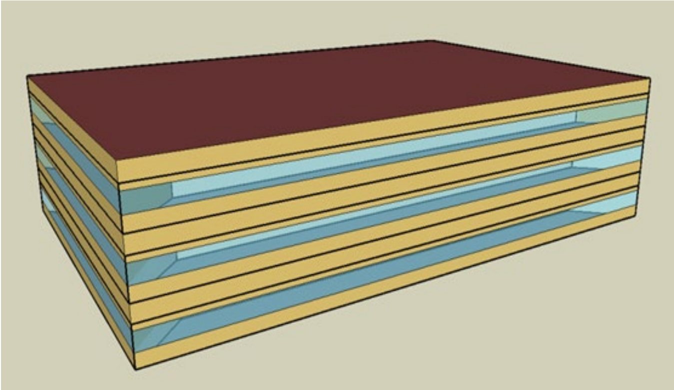
Design Example
(3-story office building)

Structure: Steel Frame Walls with Concrete Slab Floors



NOTE: All cases include metal stud clear field thermal bridges within U-factor for assembly

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

Transmittance Type	Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Heat Flow (BTU/ hr°F)	%Total Heat Flow
Clear Field	Opaque Wall Area (R13 cavity insulation only)	14267.00	ft^2	0.124	BTU/ hr ft^2 °F	1769.1	100%

Overall Opaque Wall Thermal Performance	
Opaque U-Value (BTU/hr ft^2 °F)	0.124
Effective R-Value (hr ft^2 °F/BTU)	8.1

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

Transmittance Type	Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Heat Flow (BTU/ hr°F)	%Total Heat Flow
Clear Field	Opaque Wall Area (R13+10 per ASHRAE 90.1)	14267.00	ft^2	0.055	BTU/ hr ft^2 °F	784.7	100%

Overall Opaque Wall Thermal Performance	
Opaque U-Value (BTU/hr ft^2 °F)	0.055
Effective R-Value (hr ft^2 °F/BTU)	18.2

Case 2 mitigates the clear-field framing thermal bridges within the assembly.

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Design Example
(3-story office building)

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

Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Source Reference	Heat Flow (BTU/hr°F)	%Total Heat Flow
					Totals	2147.8	100%
Opaque Wall Area	14267.00	ft^2	0.055	BTU/ hr ft^2 °F	BC Hydro	784.7	37%
Opaque Roof – Opaque Wall Intersection (Parapet)	546.00	ft	0.400	BTU/ hr ft °F	2.2.3	218.4	10%
Opaque Wall – Above-grade Floor Intersection	1638.00	ft	0.500	BTU/ hr ft °F	5.2.25	819.0	38%
Opaque Wall – Interior Wall Intersection	156.00	ft	0.134	BTU/ hr ft °F	5.8.1	0.0	0%
Opaque Wall - Balcony Intersection	197.00	ft	0.600	BTU/ hr ft °F	5.2.5	118.2	6%
Opaque Wall - Horizontal Fenestration Intersection	1092.00	ft	0.190	BTU/ hr ft °F	5.3.1	207.5	10%

Overall Opaque Wall Thermal Performance*	
Opaque U-Value (BTU/hr ft^2 °F)	0.151
Effective R-Value (hr ft^2 °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

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Design Example
(3-story office building)

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

Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Source Reference	Heat Flow (BTU/hr°F)	%Total Heat Flow
					Totals	1042.5	100%
Opaque Wall Area	14267.00	ft^2	0.055	BTU/ hr ft^2 °F	BC Hydro	784.7	75%
Opaque Roof – Opaque Wall Intersection (Parapet)	546.00	ft	0.150	BTU/ hr ft °F	5.5.11	81.9	8%
Opaque Wall – Above-grade Floor Intersection	1638.00	ft	0.020	BTU/ hr ft °F	5.3.3	32.8	3%
Opaque Wall – Interior Wall Intersection	156.00	ft	0.134	BTU/ hr ft °F	5.8.1	0.0	0%
Opaque Wall - Balcony Intersection	197.00	ft	0.117	BTU/ hr ft °F	5.2.13	23.0	2%
Opaque Wall - Horizontal Fenestration Intersection	1092.00	ft	0.110	BTU/ hr ft °F	5.3.8	120.1	12%

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 <u>mitigated</u> linear thermal bridges at wall-to-floor, -fenestration, and -roof assembly intersections

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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 with continuous insulation can significantly improve (e.g., double) building thermal 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 (i.e., "a thicker bucket with holes will still leak water at nearly the same rate").
- Several sources of data and design guidance are available to support appropriate consideration and mitigation of thermal bridges (see Bibliography).
- New energy codes and standards have changed to better address thermal bridging effects.

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- Repetitive Metal Penetrations in Building Thermal Envelope Assemblies, ABTG Research Report No. 1510-03, Applied Building Technology Group LLC, 2016
- Attachment of Exterior Wall Coverings Through Foam Plastic Insulating Sheathing (FPIS) to Wood or Steel Wall Framing, ABTG Research Report No. 1503-02, Applied Building Technology Group LLC, 2019.

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Questions?

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