ACI/TMS Code 122.1-21

Thermal Bridge Mitigation for Buildings Having Concrete and Masonry Walls and Masonry Veneer

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Overview

- Background of development
- Examples of thermal bridges
- Chapter 1: Scope and purpose
- Section 4.1: Climate zones
- Section 4.2: Compliance paths and exemptions
- Section 4.3: U-factors for assemblies with thermal bridges
- Chapter 5: Prescriptive path (just tell user what to do)
- Chapter 6: Envelope tradeoff method (e.g., COMcheck)
- Chapter 7: Whole building simulation (e.g., EnergyPlus)
- Benefits and suggested adoption of ACI/TMS 122.1

Development

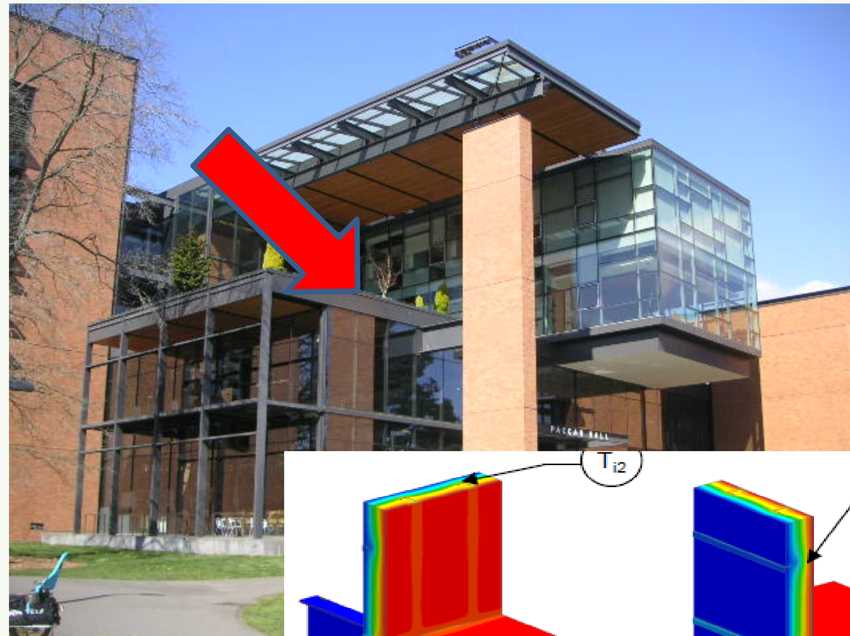
- Available at www.concrete.org, ACI store tab
- Concrete and masonry industry *stakeholders*' desire to be a *leader* in reducing energy used in building due to thermal bridges
- ASHRAE 90.1 and the IECC have provisions that require complicated and sometimes inaccurate calculations
- Developed by ACI/TMS Committee 122: Energy Efficiency of Concrete and Masonry systems

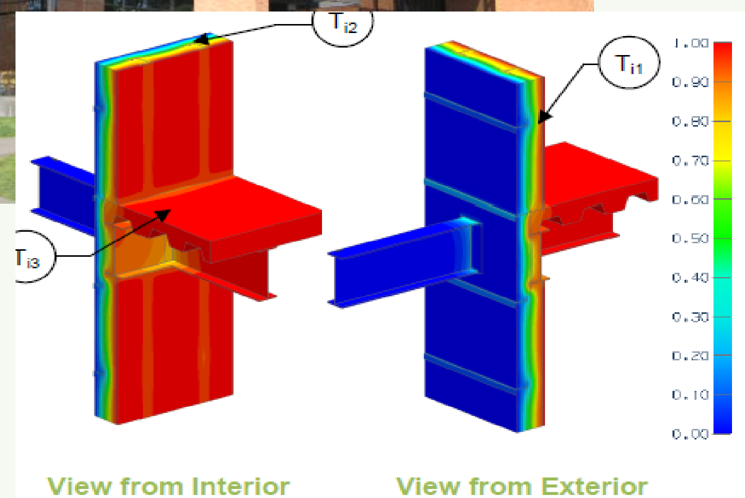
Purpose for Development

- For ACI/TMS 122.1 to be a choice by states/jurisdictions or designers for thermal bridge migitation of concrete and masonry systems
  - For adoption by jurisdictions – state and city codes
- Easier to understand and implement
- Leads to more use and better enforcement

Example of Thermal Bridge
Steel Beam Example

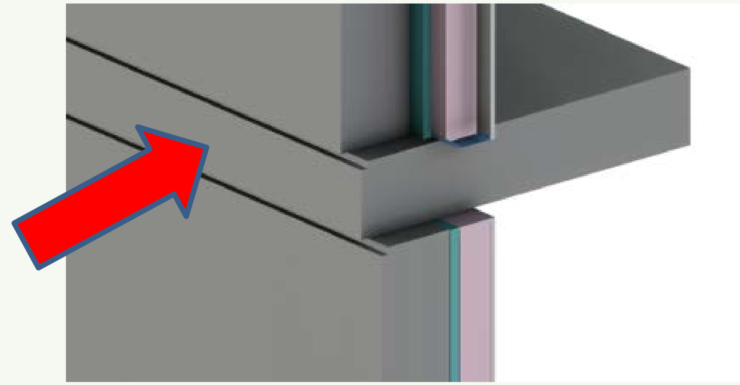
- Usually a material of higher thermal conductance penetrating insulation
- Thermal bridges can contribute to energy loss in buildings

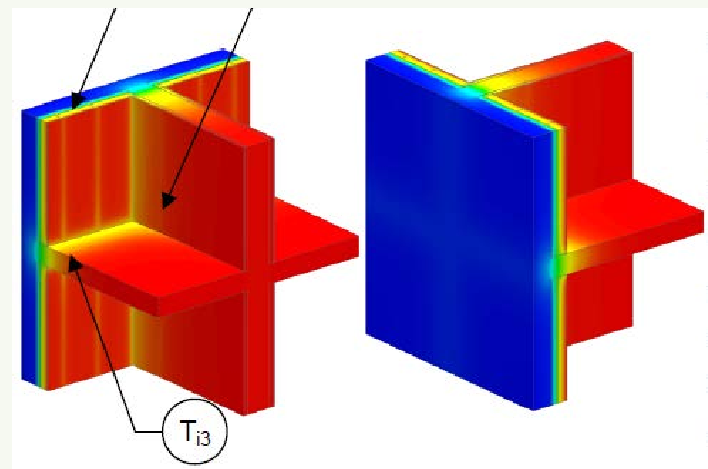




Example of Thermal Bridge
Concrete Floor Example

- Concrete floor slab edge supporting concrete wall
- Intermediate floor

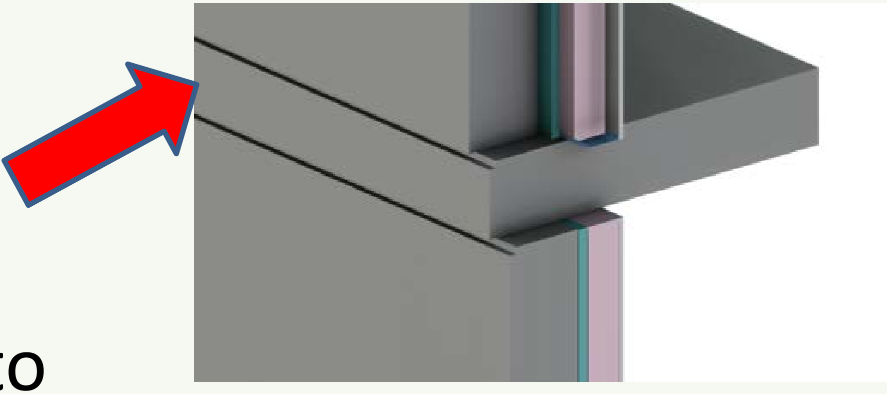




Ref. 6.2.4, psi = 0.47 Btu/hr·ft·°F

Example of Thermal Bridge Concrete Floor Example

- Conductance of concrete floor slab edge is about the same as the fenestration required by codes, per area or linear foot
- So 8 linear in. of concrete slab is about the same heat loss as 8 linear in. of fenestration (or less due to mass effects)



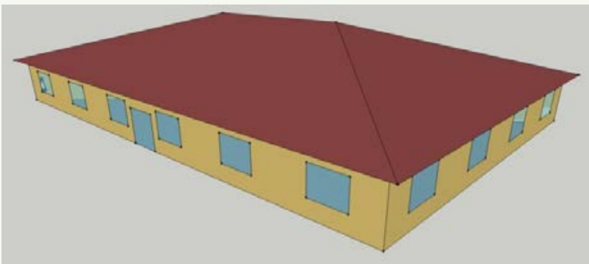
Ref. 6.2.4, psi = 0.47 Btu/hr·ft·°F

Actual Buildings Don't Meet the Ideal Case – Mixed Use

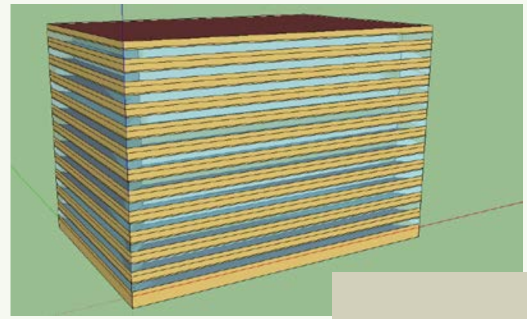
- Balconies
- Parapets
- Window sills
- Signs
- Shading devices
- Light fixtures
- Architectural features

Ideal Buildings - Models

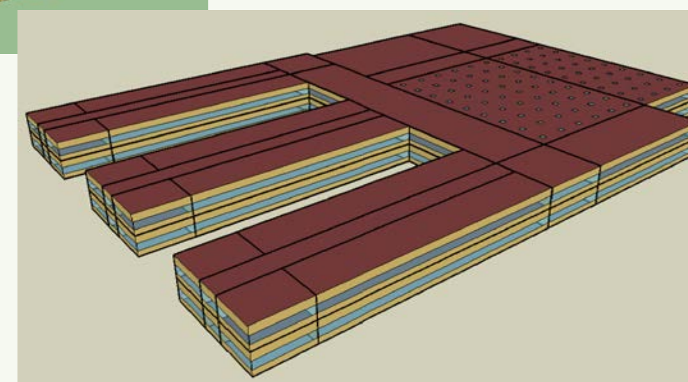
Small Office



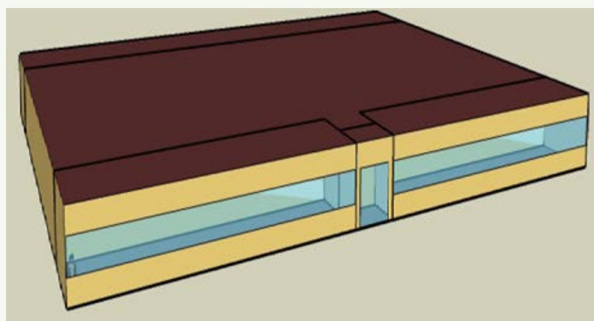
Large Office



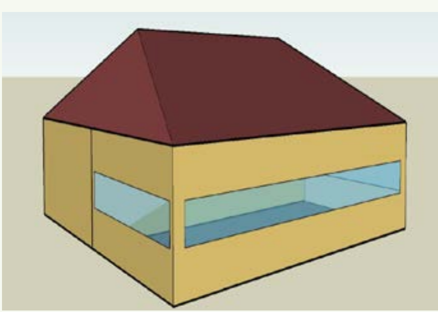
Secondary School



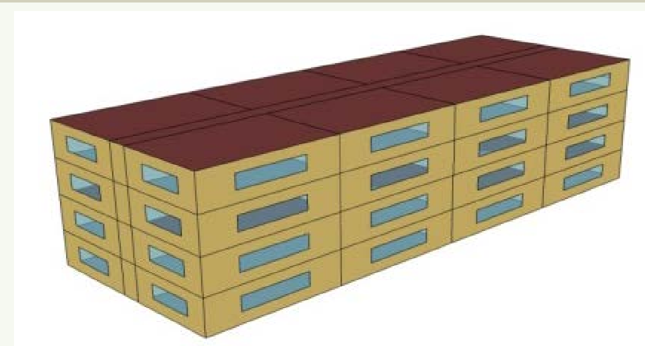
Standalone Retail



Quick-service Restaurant



Mid-rise Apartment



Actual Buildings Don’t Meet the Ideal Case – High Rise

Sign

Juliet Balcony

Awning

Actual Buildings Don't Meet the Ideal Case – Features

Exposed columns, etc.

Chapter 1: Scope and Purpose

- Minimum design and construction requirements
- For mitigating thermal bridges
- In building envelopes
- Of new buildings and additions to existing buildings
- Consisting of concrete or masonry construction
- For use with applicable energy codes and standards adopted by jurisdictions

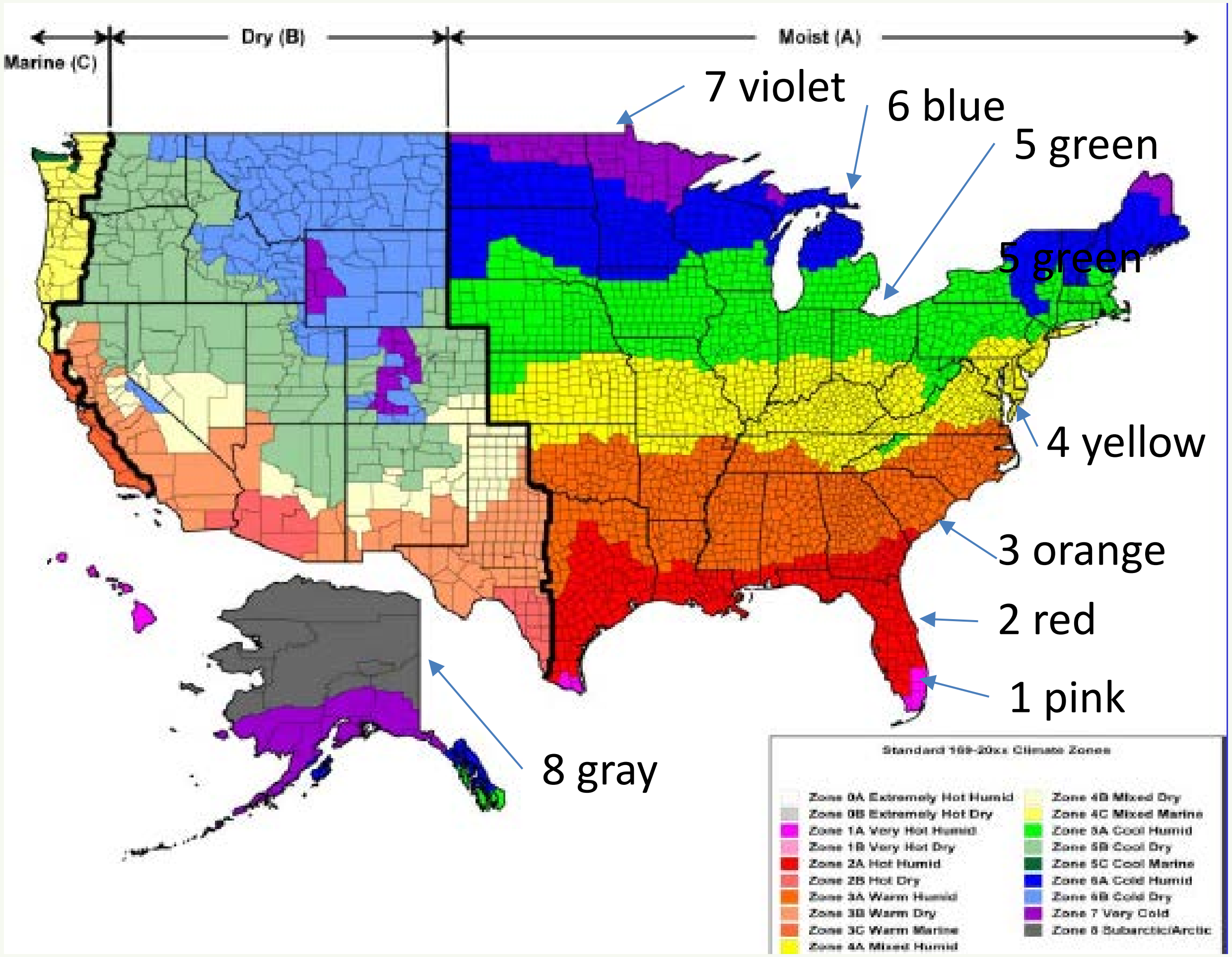
Chapter 1: Scope and Purpose

- Commercial, industrial, midrise and highrise buildings (not for residential 3 stories or less)
- With *concrete, masonry, or masonry veneer* within building envelope

Aqua building photo wikipedia

Section 4.1: Climate Zones (CZ)

- No criteria for Climate Zones 0-4
- Optimally adoptable for northern states OR option within ASHRAE 90.1 or IECC



Exempts Climate Zone 4

Does not burden CZ 4 (e.g. D.C.) with criteria

- Cooling dominated climate
- Insulation and thermal bridging mitigation less cost effective and thermal mass benefits greater
- Need more shading for cooling, which are likely thermal bridges

Cooling Costs Increasing with More Insulation - Need Shading

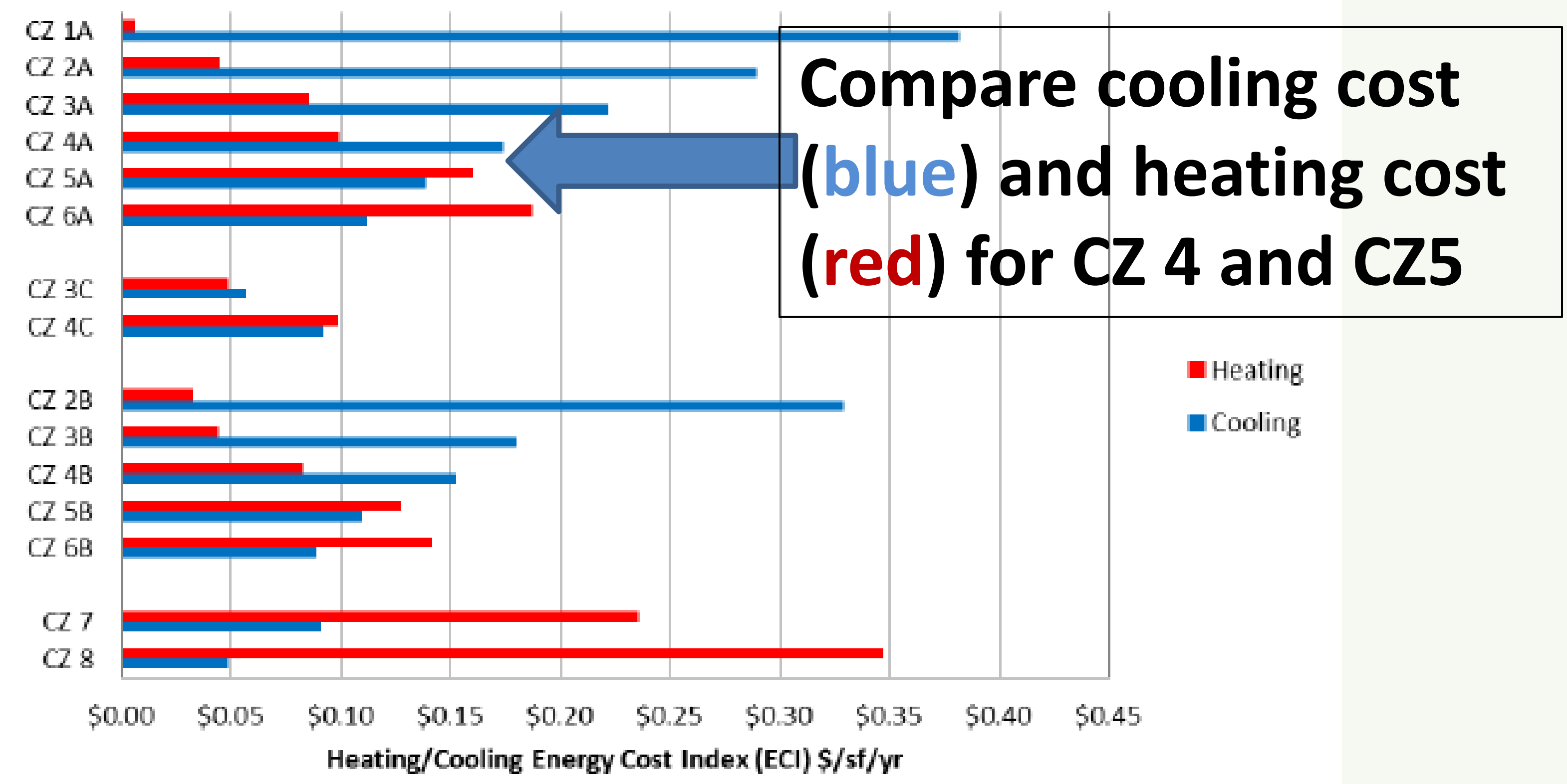


Figure 14. Building ECI heating and cooling by climate zone (CZ)

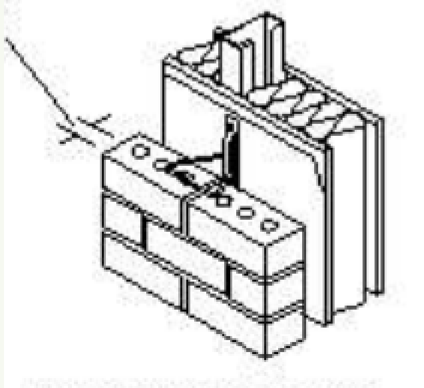
DOE, PNNL Report No. 24043, "End-Use Opportunity Analysis from Progress Indicator Results for ASHRAE Standard 90.1-2013"

Section 4.2: Three Compliance Paths

- **Use *one* of three compliance path choices:**
  a) Prescriptive (just tell user what to do)
  b) Envelope trade off (e.g., COMcheck; requires some analysis)
  c) Whole building simulation (e.g., EnergyPlus; requires high level, complicated analysis)

Section 4.2.1: Exceptions for All Compliance Paths - General

- Conditions not requiring analysis for any compliance path:
  a) *Penetrations through uninsulated building envelope*
     - No insulation is penetrated
  b) *Buildings having a percentage of vertical fenestration to gross building envelope wall area of less than 20%*
     - Walls have more insulation and less heat loss where there is less fenestration
  c) *Masonry veneer ties*



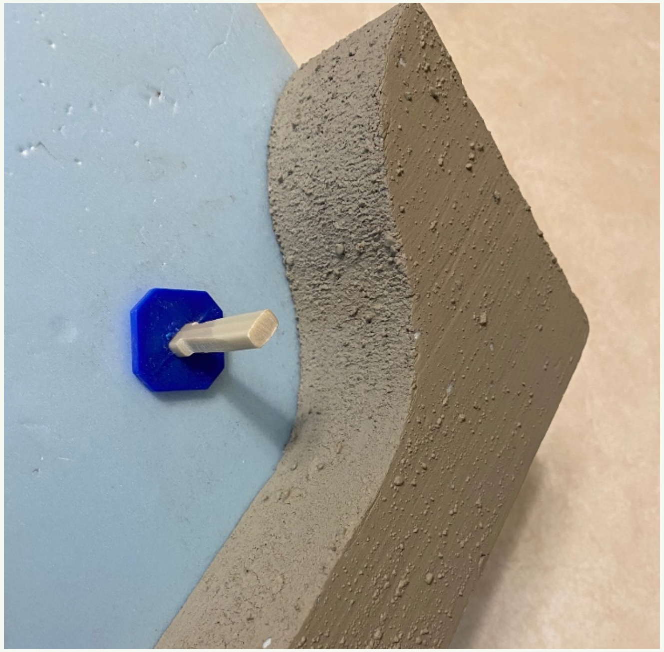
Section 4.2.1: Exceptions for All Compliance Paths – Thermal Break

- Conditions not requiring analysis for any compliance path:

  d) *Penetrations that incorporate a thermal break*

***Definition of thermal break**—a material having a thermal conductivity less than 3 Btu·in./h·ft^2·°F.*

- Generally includes wood blocking, thin layers of insulation, and fiberglass composite materials
- e.g., ICF wall or sandwich panel wall can have fiberglass composite ties



Section 4.2.1: Exceptions for All Compliance Paths - Point thermal bridges

- Conditions not requiring analysis for any compliance path:

  e) Stainless steel penetrations less than 9 in.^{2} over 10 sq ft of wall area.

  Other metal penetrations less than 3 in.^{2} over 10 sq ft of wall area

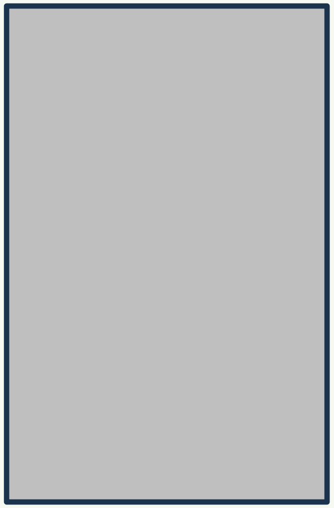
- Don’t need to count every small fastener or attachment or penetration
- Stainless steel has a lower thermal conductivity than carbon steel, so these are approximately thermally equivalent
- Use average area on each side of insulation, e.g. at line

Section 4.2.1: Exceptions for All Compliance Paths - Point thermal bridges

- Conditions not requiring analysis for any compliance path:

  f) *Normal weight concrete penetrations less than 60 in.^{2} over 10 sq ft of wall area*

  Lightweight concrete penetrations less than 120 in.^{2} over 10 sq ft of wall area



- Don't need to count every small concrete penetration
- Lightweight concrete has a lower thermal conductivity than normal weight concrete, so these are approximately equivalent; and approximately equivalent to metal allowances
- Use average area on each side of insulation

Chapter 5: Prescriptive Path

- 5.1 Roof with insulation with parapet
- 5.2 Balcony, overhang, and intermediate floor
- 5.3 Shelf angles supporting masonry veneer
- 5.4 All other thermal bridges that do not comply with 5.1, 5.2, or 5.3

Section 5.1: Roof Ins. With Parapet

- For Climate Zones 6 though 8

a) Exterior insulation extends to top of roof insulation

b) Interior insulation extends to underside of roof deck

Exception for structural connections, other elements

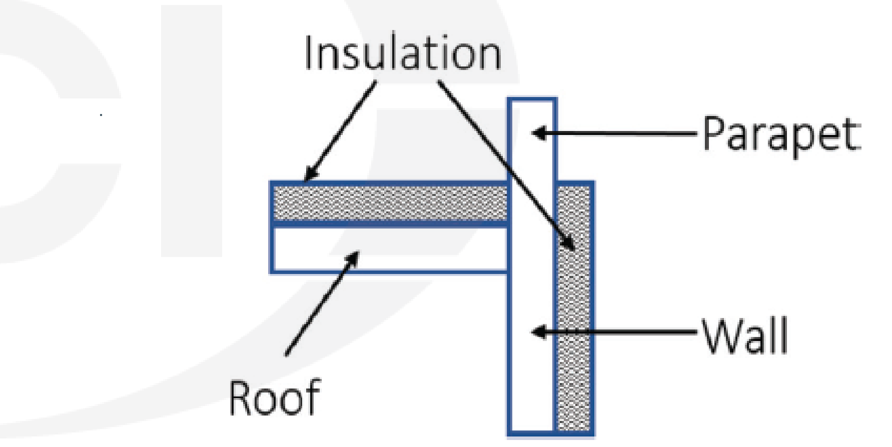


Fig. R5.1a—Exterior insulation.

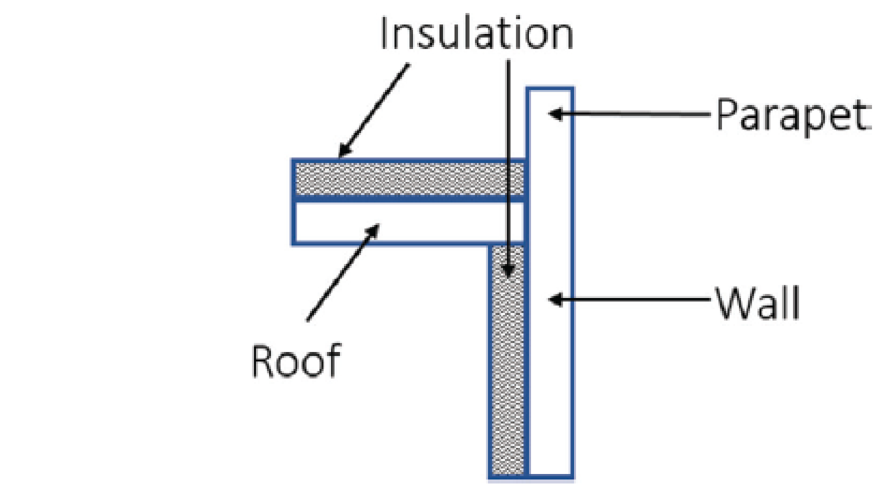


Fig. R5.1b—Interior insulation.

Section 5.1: Roof Ins. With Parapet

- For Climate Zones 6 though 8

c) Integral insulation extends to top of roof insulation

d) Insulation behind masonry veneer extends to top of roof insulation

Exception for structural connections, other elements

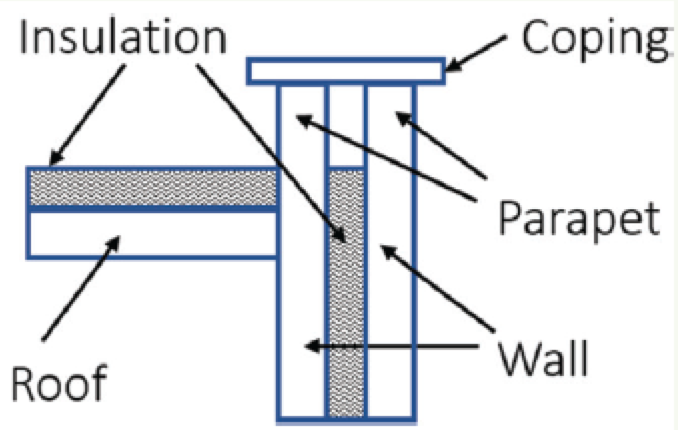


Fig. R5.1c—Integral insulation.

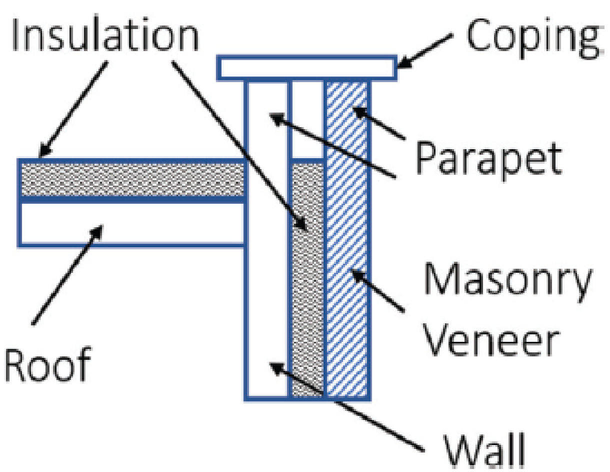


Fig. R5.1d—Insulation behind veneer.

Section 5.2: Balcony, Overhang, and Intermediate Floor

- For Climate Zones 5 though 8

a) Where 50% or more is **residential occupancy**:

  - Balconies and projections are limited to % of perimeter of building:
    - 30% in Climate Zone 5
    - 20% in Climate Zone 6
    - 10% in Climate Zone 7
    - 0% in Climate Zone 8

Section 5.2: Balcony, Overhang, and Intermediate Floor

- For Climate Zones 5 though 8

b) Where more than 50% is **commercial** occupancy:

  - Balconies and projections are limited to 10 % of perimeter of building

  - 5.2.1 Exception (a) allows for thermal breaks or R3 insulation, and structural framing and connections (all buildings)

Section 5.2: Balcony, Overhang, and Intermediate Floor

- 5.2.1 Exceptions

Balconies or projections that:

b) Are supported by an independent **gravity support system**, or by **point load connections.**

c) Are not extensions of floor slabs.

Allowed; not limited

Section 5.2: Balcony, Overhang, and Intermediate Floor

- 5.2.1 Exceptions

Balconies or projections that:

d) Provide weather protection at grade pedestrian, or street level.

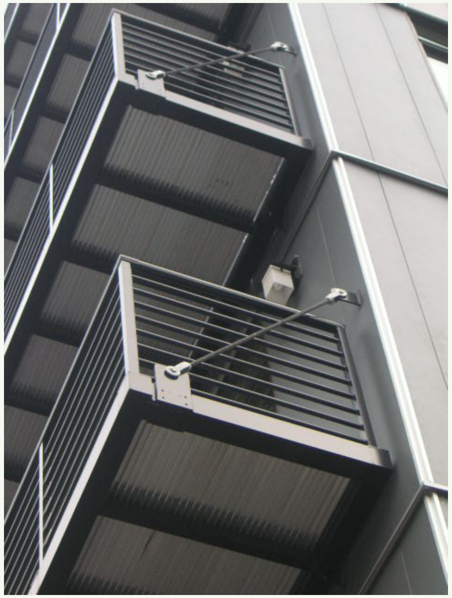
(e.g., **overhangs at entryways**)

e) Beams of any material that support **pedestrian walkways**.

Allowed; not limited

Section 1.3.2: Moisture

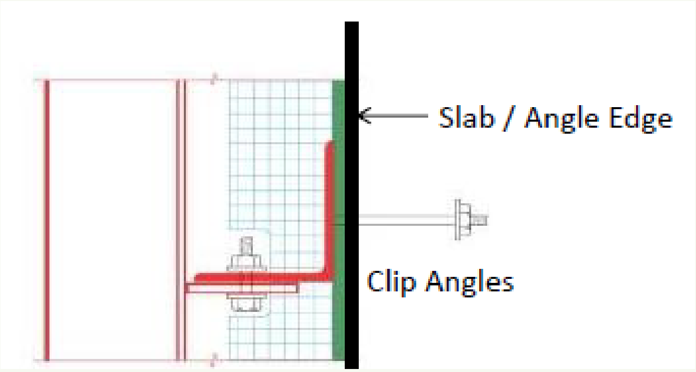
Section 1.3.2 *This code does not address moisture or condensation control, nor does it provide criteria to prevent moisture migration or condensation.*



- Be Aware: Rods and other steel connections may be subject to **condensation, rusting, and failure**, **hidden within the wall**; why we don't have fire escapes anymore.

Section 5.3: Shelf Angles Supporting Masonry Veneer

- For Climate Zones 6 though 8
- Shelf angles that support masonry veneer must allow full depth of insulation between connections
  - o Allows insulation between angle and structure



Plan View

Images courtesy of Int. Masonry Inst., used with permission

Section 5.3: Shelf Angles Supporting Masonry Veneer

5.3.1 Exceptions:

a) 25% of perimeter length of shelf angles

- Allows for building façade indentations often used for aesthetics

b) A thermal break installed along the length of the shelf angle between connections

Section 5.4: Other Thermal Bridges

- For all **other** thermal bridges not addressed by 5.1 thru 5.3 or the exemptions in Section 4.2:
  - 5.1 Roof with insulation with parapet
  - 5.2 Balcony, overhang, and intermediate floor
  - 5.3 Shelf angles supporting masonry veneer
  - 4.2 Exemptions for buildings with low fenestration, small thermal bridges, etc.
- Generally *large* steel and concrete that penetrate building envelope

Section 5.4: Other Thermal Bridges

- Requires modified calculation of U-factor (C-factor below grade) for elements with **large** thermal bridges
  - that penetrate the entire building envelope, not just the insulation.

Section 5.4: Other Thermal Bridges Exceptions

5.4.3 Exceptions

a).Where fasteners and framing are taken into account for assembly compliance

- i.e., fasteners to hold insulation in place for mass wall assemblies in ASHRAE 90.1 Appendix A

b.) Structural connections that meet Sections 5.1, 5.2, and 5.3

(and conditions in Sections 4.2.1 not requiring analysis)

Section 5.4: Other Thermal Bridges Exceptions

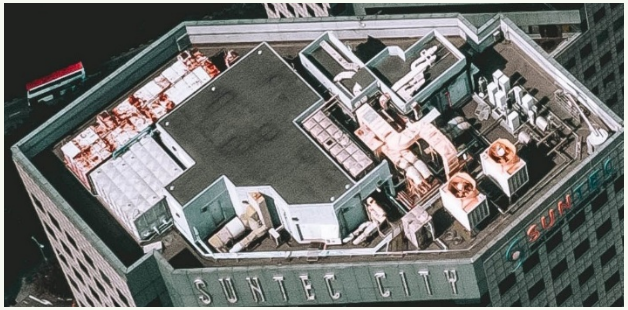
5.4.3 Exceptions

c.) Columns, beams, etc., that connect to foundation, etc.,

- e.g. corner columns

  and

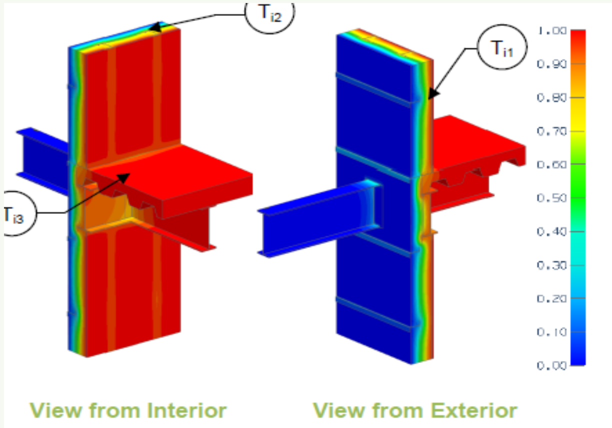
  structural connections that are part of the building envelope



d) Mechanical, electrical, plumbing, communication systems and openings that penetrate building envelope

Section 5.4: Other Thermal Bridges Calculations

- Requires modified calculation of U-factor (C-factor below grade) for elements with **large** thermal bridges
  - Modified assembly, according to Section 4.3, must comply with code
  - These complicate this prescriptive compliance path
  - Simpler to avoid them



Section 4.3: U-Factors for Assemblies Containing Thermal Bridges

- How to adjust U-factors and (C-factors below grade) for compliance with:
  - Section 5.4: Prescriptive path, other thermal bridges
  - Section 6: Envelope tradeoff method (e.g., COMcheck)
  - Section 7: Whole building simulation (e.g., EnergyPlus)
- **Seven options** including calculations and using published values
- More than other codes; sometimes more accurate

Section 4.3: Determining U-Factors Calculations

a) Two- or three-dimensional calculation method

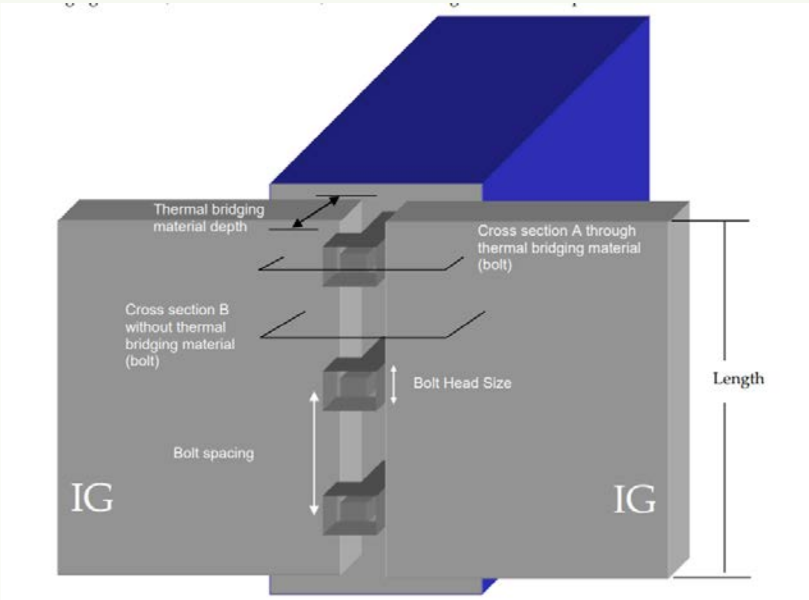
d) For concrete or masonry thermal bridges, the isothermal planes method

e) For metal, the zone or modified zone methods

- Isothermal planes (series-parallel), zone, and modified zone methods are all 2D methods
  - Described in ASHRAE Handbook of Fundamentals and other sources
  - Isothermal planes is conservative – generally too conservative for metal penetrating insulation
  - Zone method limits the “zone” for the isothermal planes

Section 4.3: Determining U-Factors Calculations

- THERM: 2D method commonly used for fenestration (LBNL)
- Example for thermal bridges in User Manual
  - Curtain wall attachment
  - Isothermal planes
  - Cross section of insulation (gray) with bolts (dark gray)



Section 4.3: Determining U-Factors Predetermined Values

b) Laboratory testing

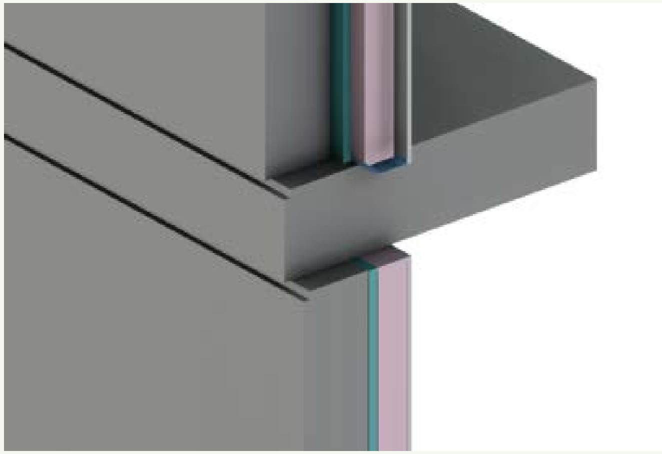
- Such as a calibrated hot box, but these are for one system at a time

c) A published value from a guide, handbook, specification, government publication, or peer-reviewed publication

- BC Hydro has an extensive catalogue
  - Actual value depends on the amount of wall insulation and the type of assembly. Not all of these variations are listed.
  - Based on a steady-state analysis and do not consider thermal mass effects

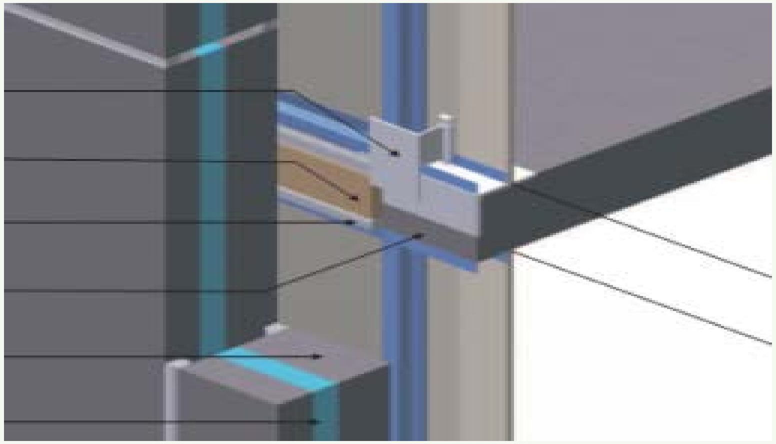
Section 4.3: Determining U-Factors Predetermined Values

- Intermediate floor at mass wall per BC Hydro:
  - o Unmitigated versus mitigated psi factors
  - o Value depends on amount of insulation, etc.; not all listed



Ref. 6.2.4, psi = 0.476 Btu/hr·ft·°F

Unmitigated

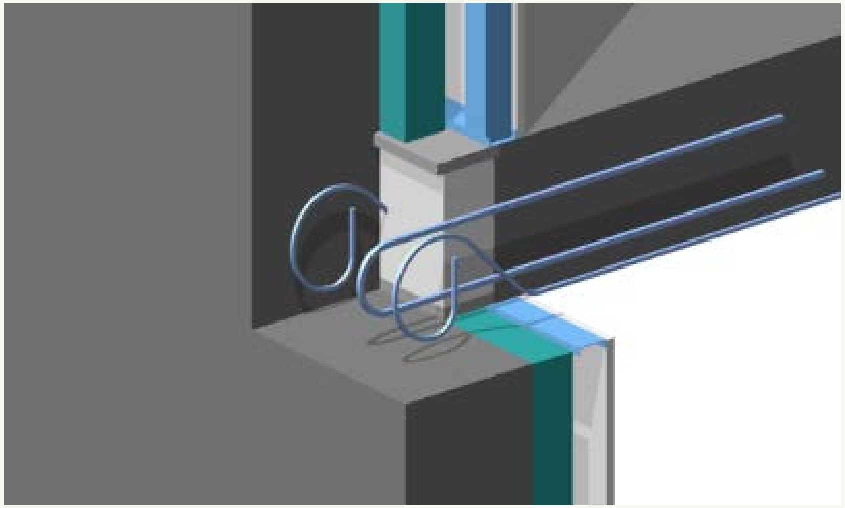


Ref. 6.2.8, psi = 0.118 Btu/hr·ft·°F

Mitigated

Section 4.3: Determining U-Factors Predetermined Values

- Manufactured thermal break – improved
  - psi factor: heat flow per linear ft
  - depends on R-value of insulation in wall and in thermal break, thickness of slab, sliding glass door.
  - Not all in BC Hydro



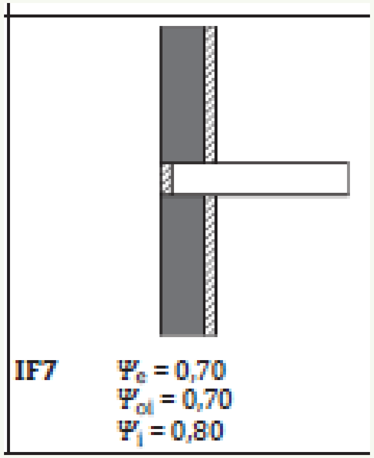
Ref. 6.2.20, psi = 0.179 Btu/hr·ft·°F

Section 4.3: Determining U-Factors

f) ISO 10211: Thermal Bridges in Building Construction – Heat Flows and Surface Temperatures – ***Detailed Calculations***

- Provides rules on performing 2D and 3D analysis
- Even BC Hydro does not comply

g) ISO 14683: Thermal Bridges in Building Construction – Linear Thermal Transmittance – ***Simplified Methods and Default Values***



- Provides simplified methods
- Provides psi and chi values for some assemblies

Chapter 6: Building Envelope Tradeoff

- Allows using more insulation or better fenestration to counter heat loss through thermal bridges
- Requires use of method in applicable code
  - COMcheck is usually used
- The only thermal bridges required to be modeled separately are those not meeting Sections 4.2.1 (Conditions not requiring analysis) nor complying with Chapter 5

Chapter 6: Building Envelope Tradeoff

- Enter assembly with thermal bridge as:
  - Separate element
  - U-factor for assembly including thermal bridge (only most recent version of codes in COMcheck)

Chapter 6: Building Envelope Tradeoff

Enter thermal bridge as separate element

- Enter area of concrete thermal bridge that exceeds Chapter 4f exception (60 sq in) as new wall with area (1 sq ft) and U-factor (0.58)

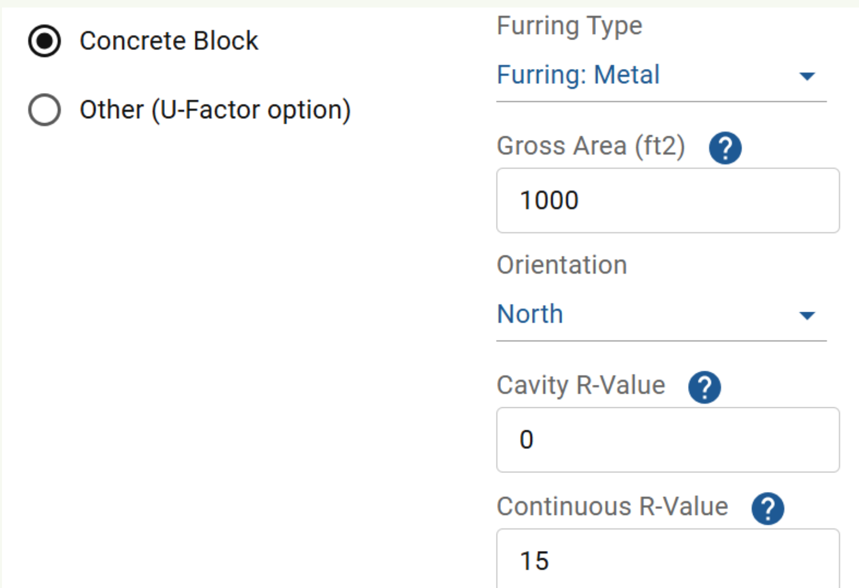
Assemblies

COMcheck

		Assembly	Gross Area	Orientation	Cavity R-Value	Continuous R-Value	Clear U-Factor
1	☐	Exterior Wall MASONRY	1000	NORTH	0	15	0.055
2	☐	Exterior Wall 1 OTHER:OTHER WALL	1	SOUTH	0	0	0.58

Chapter 6: Building Envelope Tradeoff

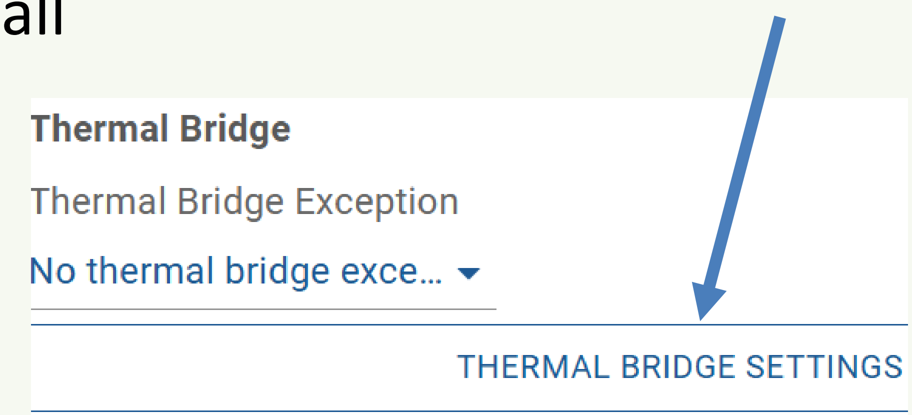
Enter assembly with thermal bridge as assembly U-factor: wall example



Chapter 6: Building Envelope Tradeoff

Enter assembly with thermal bridge as assembly U-factor: wall example (cont.)

- Under thermal bridge settings, select one:
  - o Roof edge
  - o Parapet
  - o Intermediate floor at wall
  - o Balcony or overhang at wall
  - o Balcony at fenestration
  - o Cladding support
  - o Wall to fenestration
  - o Other



Chapter 6: Building Envelope Tradeoff

Enter assembly with thermal bridge as assembly U-factor; wall example (cont.)

	Thermal Bridge	Thermal Bridge Type
☑	Roof Edge	Linear

COMcheck

Requires psi factors.

- Some default values in ASHRAE 90.1

Thermal Bridge Factors	Length (linear feet) or Numbers of Points
0.5 Psi-Factor	30

Chapter 7: Whole Building Simulation Method

- Requires modeling entire building
  - HVAC, lighting, and envelope
- Allows using better mechanical equipment to counter heat loss through walls or thermal bridges
  - e.g., EnergyPlus or DOE2-based programs/eQUEST using ASHRAE 90.1 Appendix G (used for LEED)
- Complicated and expensive
- Provides most flexibility

Chapter 7: Whole Building Simulation Method

- Similar to Chapter 6:
  - The only thermal bridges required to be modeled separately are those not meeting Sections 4.2.1 (Conditions not requiring analysis) nor complying with Chapter 5
  - Enter assembly with thermal bridge as:
    - Separate element
    - U-factor or thermal conductivity for assembly with thermal bridge

Chapter 7: Whole Building Simulation Method – NOTE!

- If only U-factors or R-values are input, the programs perform a **steady-state analysis**, which does not account for the beneficial thermal mass effects of concrete and masonry
- For a **dynamic temperature analysis** (24-hr temperature changes) with **mass effects**, thermal conductivity, specific heat, and density of each building envelope material must be entered
- Dynamic temperature analysis also important for **wind and solar energy renewable energy** concerns – the sun does not shine in the evening

Summary: Three Compliance Paths

- **Use *one* of three compliance path choices:**
  a) Prescriptive (just tell user what to do)
  b) Envelope trade off (e.g., COMcheck; requires some analysis)
  c) Whole building simulation (e.g., EnergyPlus; requires high level, complicated analysis)

Benefits of ACI 122.1

1.) Concrete and masonry industry *stakeholders*' desire to be a *leader* in reducing energy used in building due to thermal bridges

2.) Provides practical and flexible options:

- In prescriptive path
- For how to calculate U-factor of thermal bridge or with thermal bridge when needed

Benefits of ACI 122.1

3.) Easier to understand and implement

- Leads to more use and better enforcement
  - Less confusion leads to more acceptance by building community

ACI 122.1

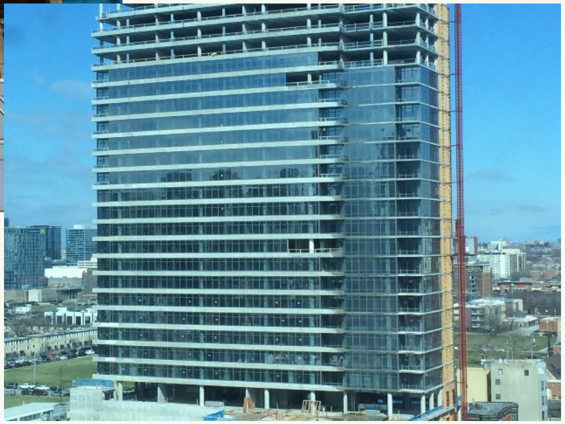
Benefits of ACI 122.1

3.) Easier to understand and implement

- Better enforcement leads to
  - More energy savings
  - Less global warming potential
  - Savings on energy bills

Benefits of ACI 122.1

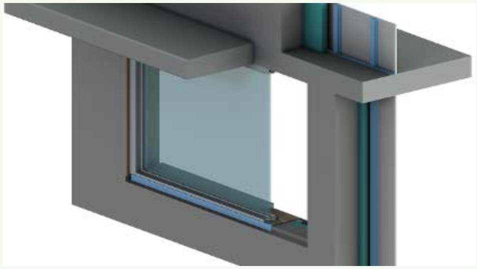
4.) Goal of 122.1 is to capture major thermal bridges keeping in mind fenestration and spandrel connection is largest thermal bridge



Benefits of ACI 122.1

5.) Technical benefits

- Doesn’t require use of psi and chi factors
  - These are complicated
  - Not enough psi or chi factors available for accurate analysis; forced to rely on ***default*** “unmitigated” and “mitigated” values which are probably not accurate since they are limited
  - Based on steady-state analysis
- Doesn’t require structurally challenging details around window frame



Benefits of ACI 122.1

6.) Does not burden CZ 4 (e.g. D.C.) with criteria

- Cooling dominated climate
- Insulation and thermal bridging mitigation less cost effective and thermal mass benefits greater
- Need more shading for cooling, which are likely thermal bridges

Cooling Costs Increasing with More Insulation - Need Shading

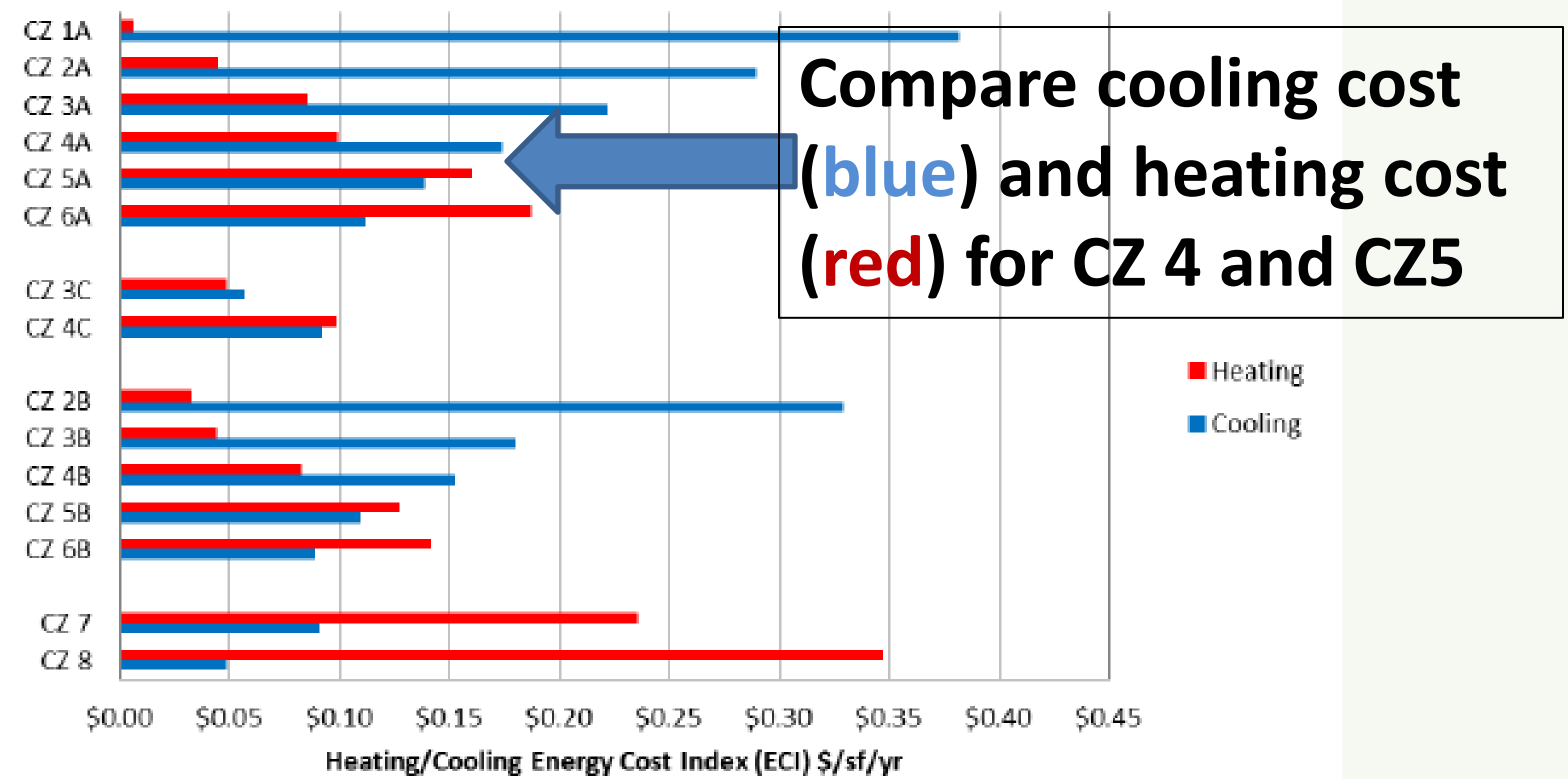
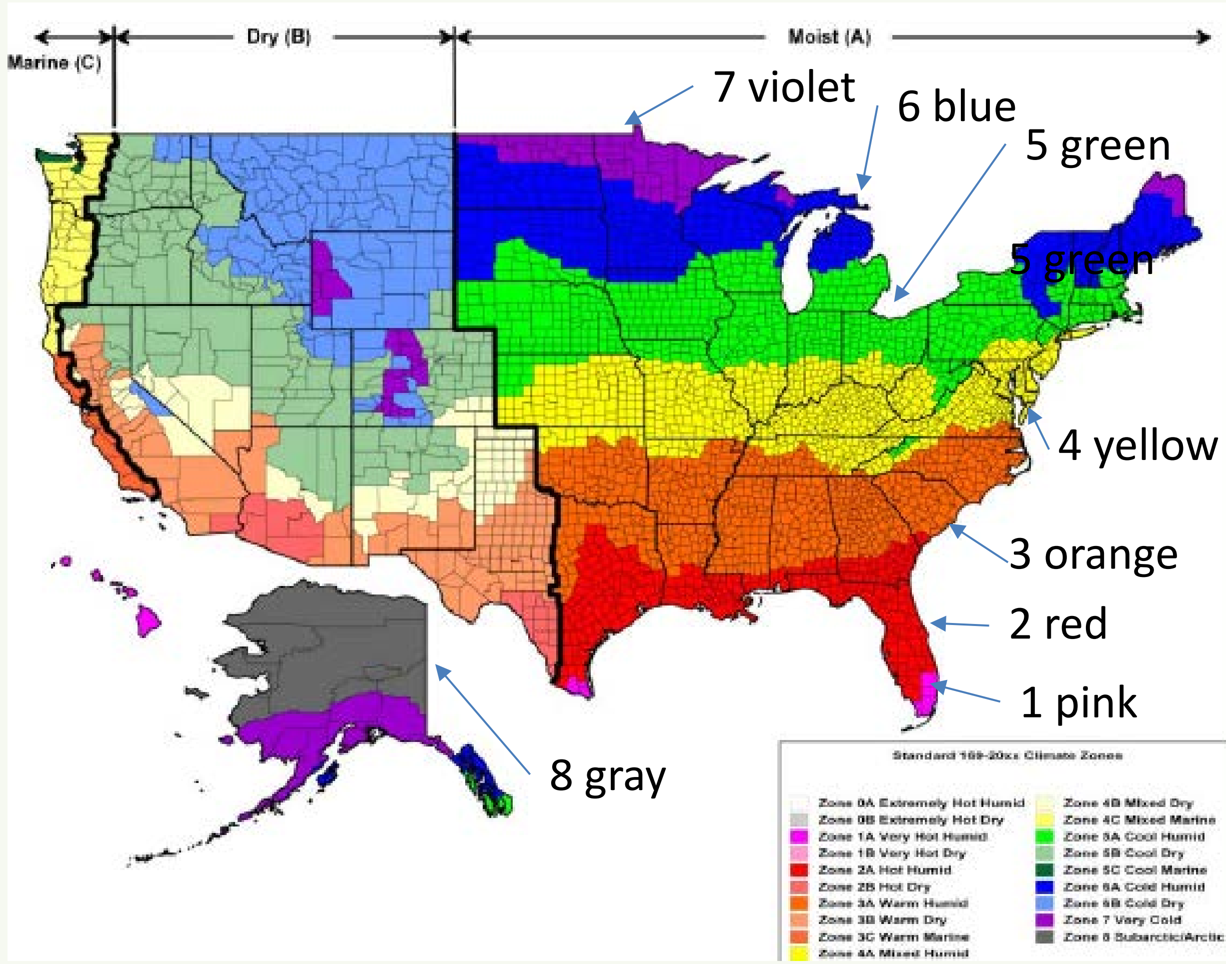


Figure 14. Building ECI heating and cooling by climate zone (CZ)

DOE, PNNL Report No. 24043, “End-Use Opportunity Analysis from Progress Indicator Results for ASHRAE Standard 90.1-2013”

Potential Adoption

- No criteria for Climate Zones 0-4
- Optimally adoptable for northern states OR option within ASHRAE 90.1 or IECC



Potential Adoption Locations

- States for adoption with CZ 5 or colder:
  - Virginia, Kentucky, Missouri, Kansas, New Mexico, Arizona, Nevada, and states north of these (approx. 37 states)
- Jurisdictions (cities) within these states
- Possible text for base code

X. Thermal bridges shall comply with one of the following:

X.1 Section XXX of base code

X.2 ACI/TMS 122.1

Questions

ACI/TMS 122.1 available at www.concrete.org, ACI store tab

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