A comparison of Calculation Methods for Thermal Bridges in Building Enclosures

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agenda

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies: Calculation Methods and Results
- MA Stretch Energy Code and PHIUS
- Conclusions

Presentation Outline

What are thermal bridges?

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies: Calculation Methods and Results
- MA Stretch Energy Code & PHIUS
- Conclusions, Implications, and Future Use

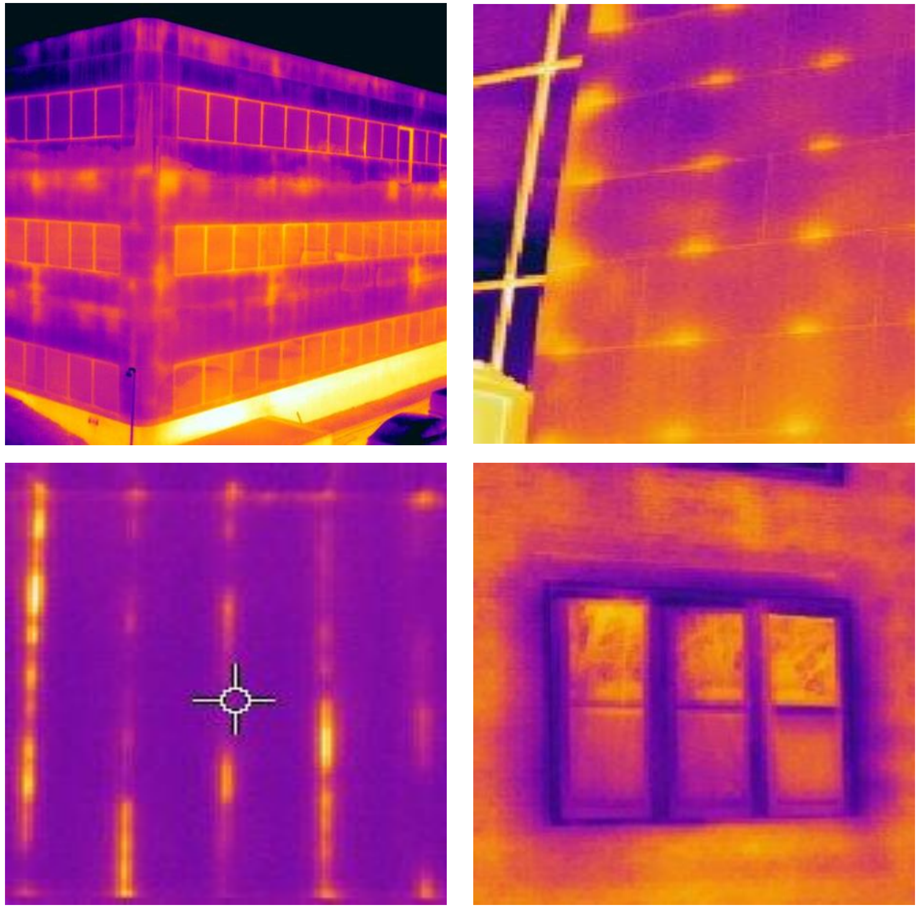
Definition

Part of the building envelope where otherwise uniform thermal resistance is changed due to:

Full or partial **penetration** of the insulating layers by materials with lower thermal conductivities;

Change in thickness of the insulating layers;

Difference between **interior and exterior areas** of the envelope (e.g., at wall/floor/ceiling junctions).



** As defined in Building Envelope Thermal Bridging Guide v. 1.6, 2021*

Why do we care?

- **Different requirements by location/jurisdiction**
  - Reporting and/or accounting for in the energy code compliance path
- **Energy Performance**
  - Effective R-value reduction (heat loss increases with additional insulation
  - Excess heat flow = wasted energy and expense
- **Occupant Thermal Comfort**
  - Cold interior surfaces, drafts
- **Building Durability**
  - Condensation, mold, indoor air quality

Thermal Bridges

Clear Field Transmittance (U_0)

Heat flow from the enclosure assembly including the effects of **uniformly distributed** thermal bridging components that are **not practical** to account for on an **individual** basis.

Heat flow per **area**

Examples:
- Brick ties, z-girts
- Exterior wall structural framing
- Structural cladding attachments

Linear Transmittance (Ψ)

Heat flow caused by details that are **linear**, can be defined by a **length along a plane** of the building envelope. Typically occur at **interfaces**.

Heat flow per **length**

Examples:
- Slab edges
- Corners
- Parapets
- Transitions between assemblies

Point Transmittance (χ)

Heat flow caused by discrete thermal bridges that occur only at **single, infrequent** locations. **Feasible** to account for on an **individual** basis.

Heat flow divided by **temperature difference**

Examples:
- Structural penetrations

Linear and Point Thermal Transmittance Method

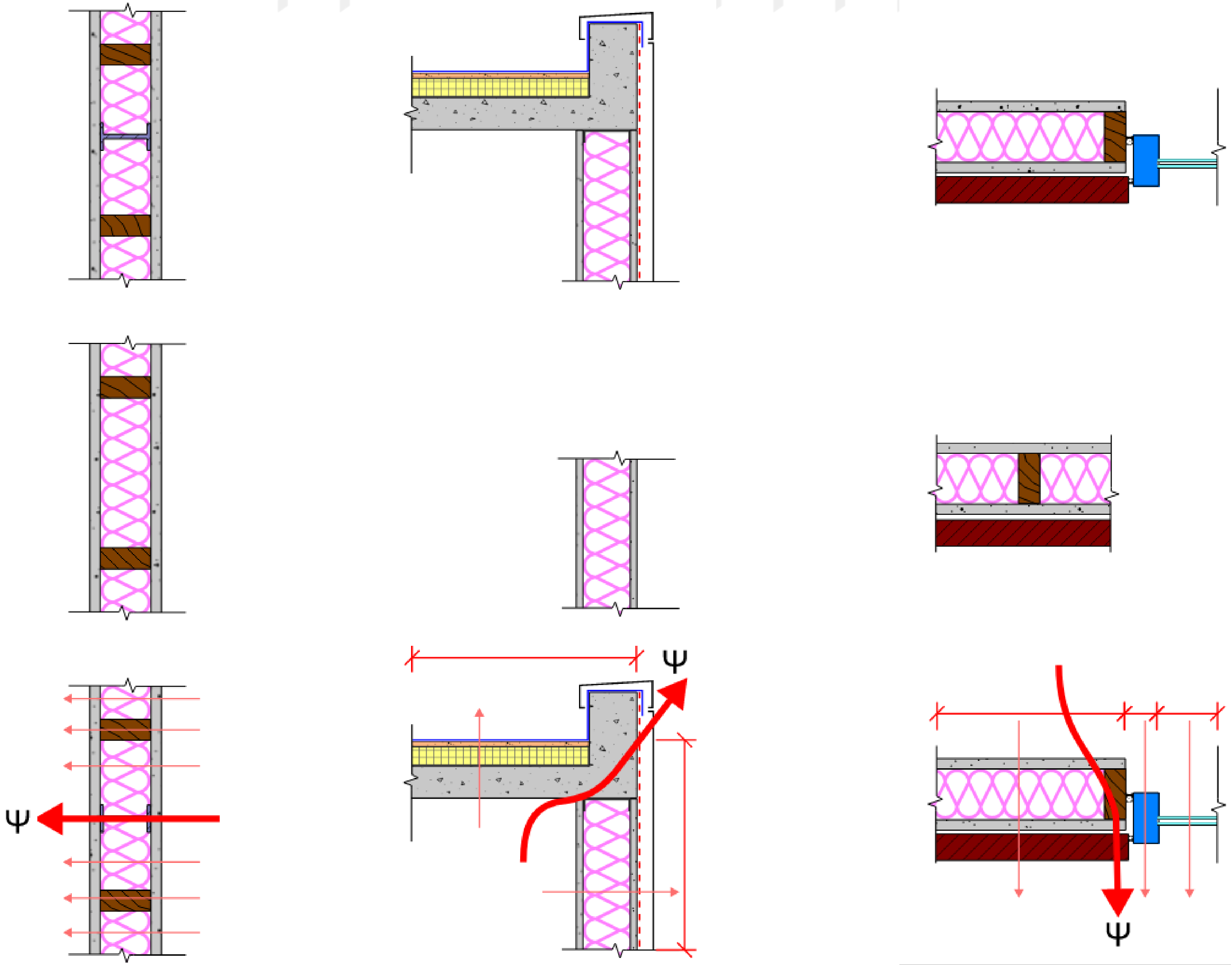
Assembly with Thermal Bridge

−

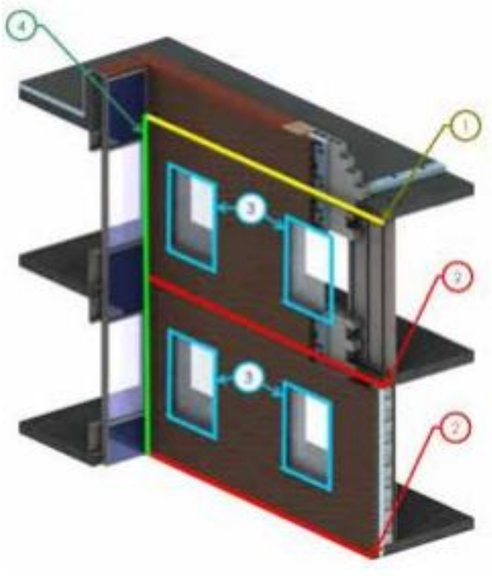
Clear Field Assembly

=

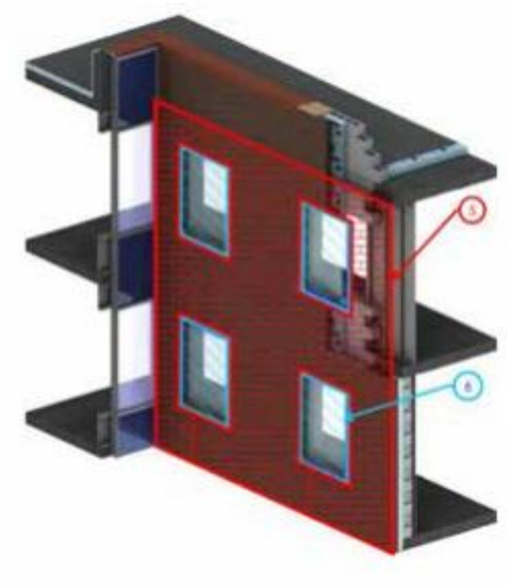
PSI-Value



Linear and Point Thermal Transmittance Method



1. Parapet Length
2. Slab Lengths
3. Wall to Window Transition Lengths



4. Corner Length
5. Opaque Brick Wall Area
6. Glazing Area

Building Envelope Thermal Bridging Guide v. 1.6, 2021

Overall thermal performance

$$U_T = \frac{\sum(\Psi * L) + \sum(\chi)}{A_{Total}} + U_0$$

Where:

U_T =	total effective assembly thermal transmittance (Btu/hr·ft^2·°F or W/m^{2}K)
U_o =	clear field thermal transmittance (Btu/hr·ft^2·°F or W/m^{2}K)
A_{total} =	the total opaque wall area (ft^2 or m^2)
Ψ =	heat flow from linear thermal bridge (Btu/hr·ft °F or W/mK)
L =	length of linear thermal bridge, i.e. slab width (ft or m)
χ =	heat flow from point thermal bridge (Btu/hr· °F or W/K)

Presentation Outline

What is required by code?
What information is available from industry standards?

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies: Calculation Methods and Results
- MA Stretch Energy Code & PHIUS
- Conclusions, Implications, and Future Use

Code requirements, standards, & references
Requirements for thermal Bridges

In Effect

- United States
  - 2023 MA Stretch Energy Code
  - 2020 NYC Energy Conservation Code
  - 2017 DC Energy Conservation Code
  - 2018 Seattle Energy Code
- Canada
  - Toronto Green Standard Versions 3 & 4
  - Vancouver Energy Modeling Guidelines
- Standards
  - PHIUS CORE
  - ANSI/ASHRAE/IES Addendum AV to ANSI/ASHRAE/IES Standard 90.1-2019
  - ANSI/ASHRAE/IES Standard 90.1-2022

Proposed and/or Upcoming

- United States
  - Wisconsin Dept. of Safety and Prof. Services (SPS), Ch. 363
- Standards
  - ANSI/ASHRAE/IES Standard 90.1-2022
  - IECC 2024
  - ASHRAE 227P

Summary of methodologies

Default Values & Manual Calculation Methods

- 2023 MA Stretch Energy Code
- 2020 NYC Energy Conservation Code
- 2017 DC Energy Conservation Code
- ANSI/ASHRAE/IES Standard 90.1-2022

Thermal Bridge Catalogues

- ASHRAE RP-1365
- Building Envelope Thermal Bridging Guide
- ISO 14683

Numerical Calculation Guides

- ISO 10211
- CSA Z5010:21

Default values

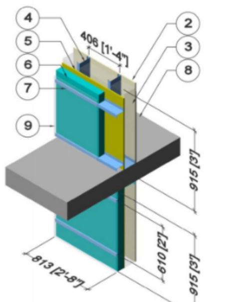
Typically based on Results Provided in Thermal Bridge Catalogues!

Thermal Bridge	2020 NYCECC	2023 MA Stretch	ASHRAE 90.1-2022 (Unmitigated / Default)			
			Steel-framed and metal buildings	Mass (exterior or integral)	Mass (interior)	Wood-framed and Other
Balcony to Exterior Vertical Wall Intersection	0.50	1.00	0.487/0.177	0.476/0.179	0.476/0.286	--
Intermediate Floor to Exterior Vertical Wall Intersection	0.44	0.60	0.487/0.177	0.476/0.179	0.476/0.286	0.336/0.049
Fenestration to Exterior Vertical Wall Intersection	0.32	0.32	0.262/0.112	0.188/0.131	0.313/0.083	0.150/0.099
Parapet (Vertical Wall to Roof Intersection)	0.42	0.60	0.289/0.151	0.238/0.125	0.511/0.227	0.032/0.032
Brick Shelf Angle / Cladding Support	0.41	0.35	0.314/0.217	0.270/0.186	0.270/0.186	0.186/0.043
Interior Vertical Wall to Exterior Vertical Wall Intersection	--	0.50	--	--	--	--
Vertical Wall to Grade Intersection	--	0.52	--	--	--	--
Vertical Wall Plane Transition (Building Corners and Other Changes in Vertical Wall Plane)	--	0.25	--	--	--	--
Roof Edge	--	--	0.450/0.140	0.500/0.100	0.500/0.100	0.450/0.140

Thermal Bridge Catalogues

Thermal Performance of Building Envelope Details for Mid-Rise and High-Rise Buildings (1365-RP)

Detail 06 **Exterior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Wall Assembly with Horizontal Z-Girts (24" o.c.) Supporting Metal Cladding – Slab Intersection**



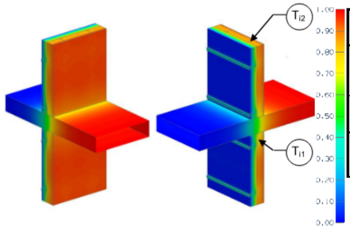
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film (right side)[1]	-	-	R-0.6 (0.11 RSI) to R-0.9 (0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	Varies	-	R-5 to R-25 (0.88 to 4.4 RSI)	1.8 (28)	0.29 (1220)
7	Horizontal Z-Girts w/ 1 ½" Flange	18 gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Concrete Slab	8" (203)	1.8	-	140 (2250)	0.20 (850)
9	Metal cladding with ½" (13mm) vented air space is incorporated into exterior heat transfer coefficient					
10	Exterior Film (left side)[1]	-	-	R-0.2 (0.03 RSI) to R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Example Detail Sheet
ASHRAE RP-1365

Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (1365-RP)

Detail 06 **Exterior Insulated 3 5/8" x 1 5/8" Steel Stud (16" O.C.) Wall Assembly with Horizontal Z-Girts (24" O.C.) Supporting Metal Cladding – Slab Intersection**



View from Interior   View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R- 3.18 (0.56 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value without slab (Detail 11)
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

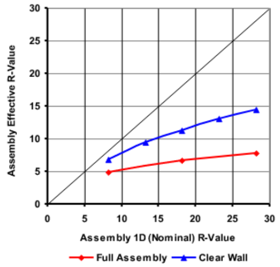
[1] Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R ft²·hr·°F / Btu (m² K / W)	U Btu/ft² ·hr ·°F (W/m² K)	ψ Btu/ft hr °F (W/m K)
R-5 (0.88)	R-8.2 (1.44)	R-6.9 (1.21)	0.146 (0.83)	R-4.74 (0.83)	0.211 (1.20)	0.433 (0.749)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)	R-6.45 (1.14)	0.155 (0.88)	0.445 (0.770)
R-25 (4.40)	R-28.2 (4.96)	R-14.6 (2.56)	0.069 (0.39)	R-7.61 (1.34)	0.131 (0.75)	0.418 (0.724)

Temperature Indices

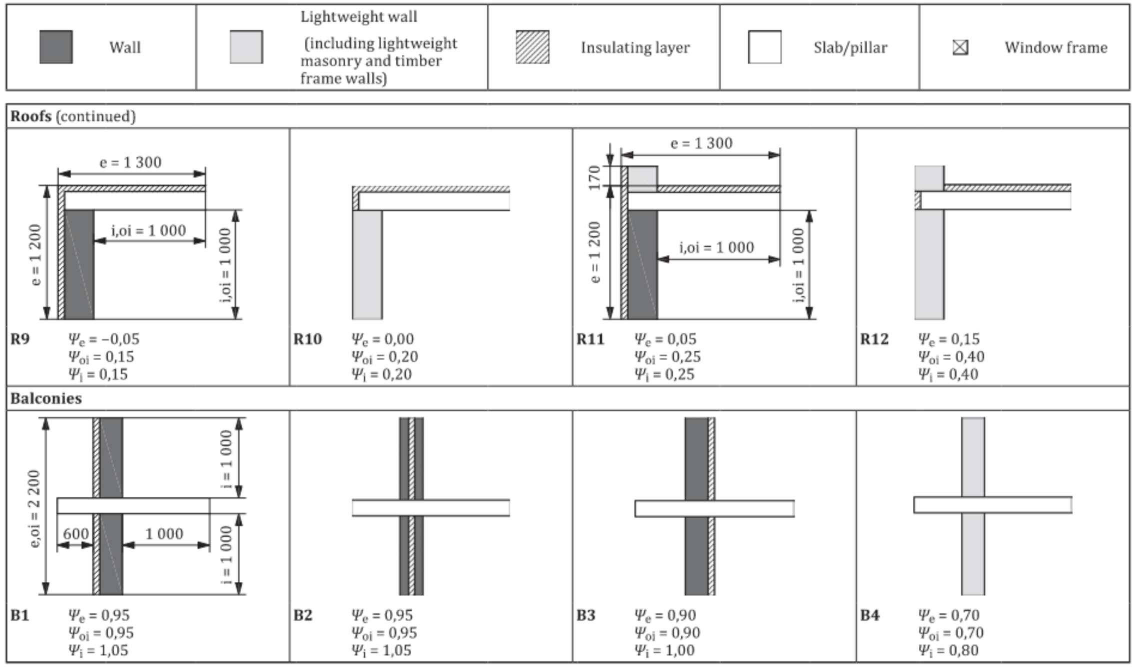
	R5	R15	R25	
T_{i1}	0.50	0.58	0.63	Min T on sheathing, at slab, between studs
T_{i2}	0.73	0.84	0.88	Max T on sheathing, at studs, between girts



Example Simulation Results Data Sheet
ASHRAE RP-1365

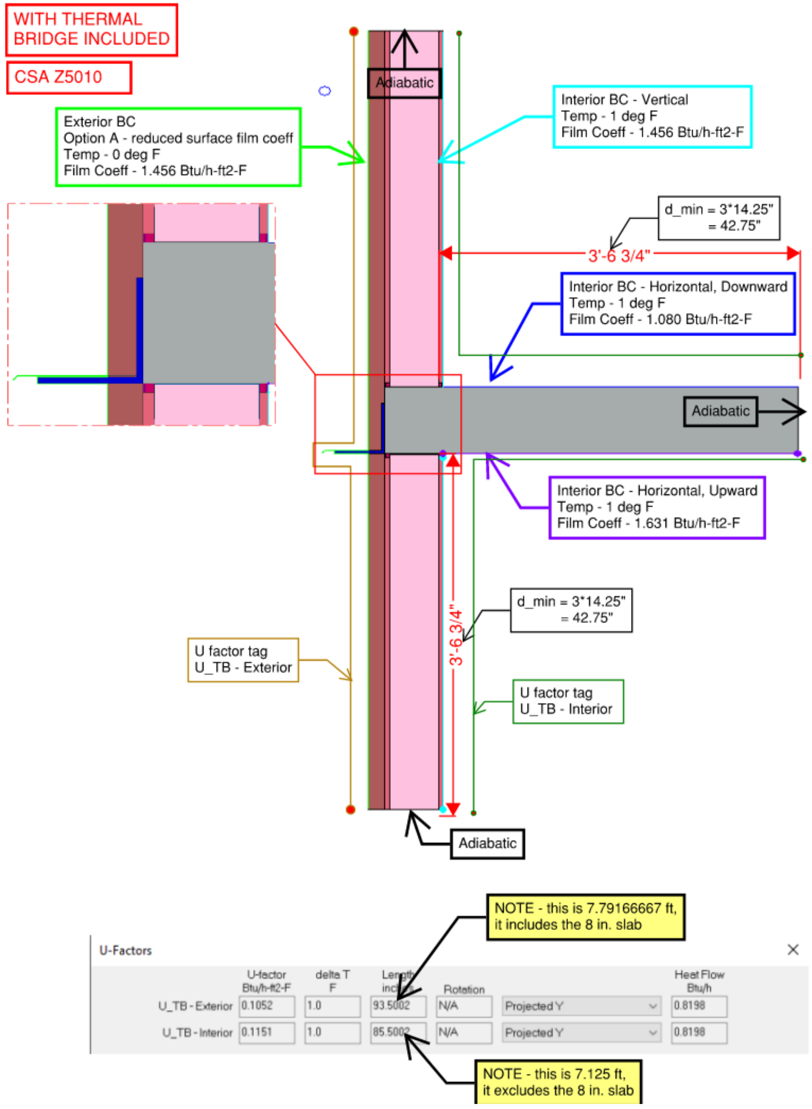
Table C.2 — *(continued)*

Dimensions in millimetres
Linear thermal transmittance in W/(m·K)

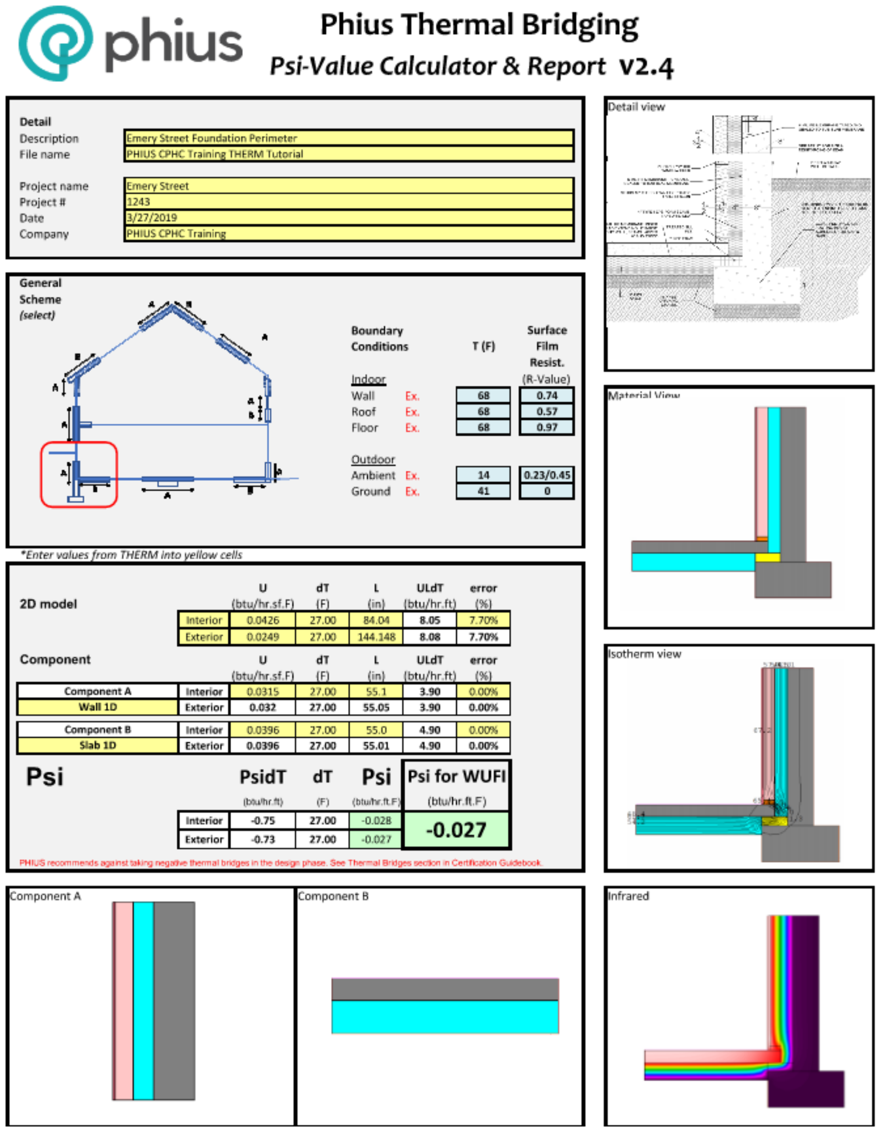


Default Values of Linear Thermal Transmittance
ISO 14683

Numerical Calculation Guides

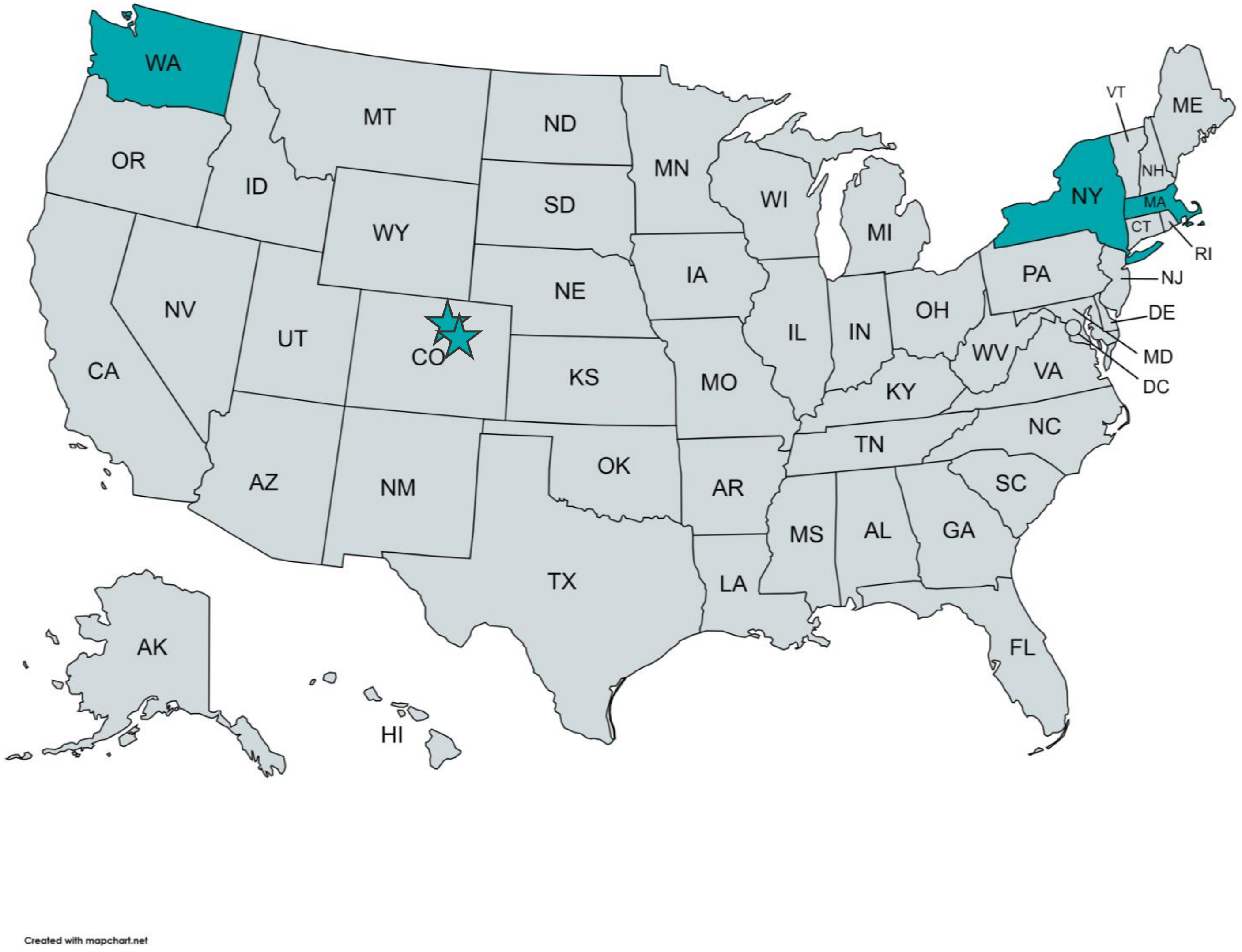


Markups over screenshot of thermal model identifying model inputs and parameters



Example calculation provided with PHIUS Psi-Value Calculator & Report

PHIUS/PHI As a Code compliance path



United States

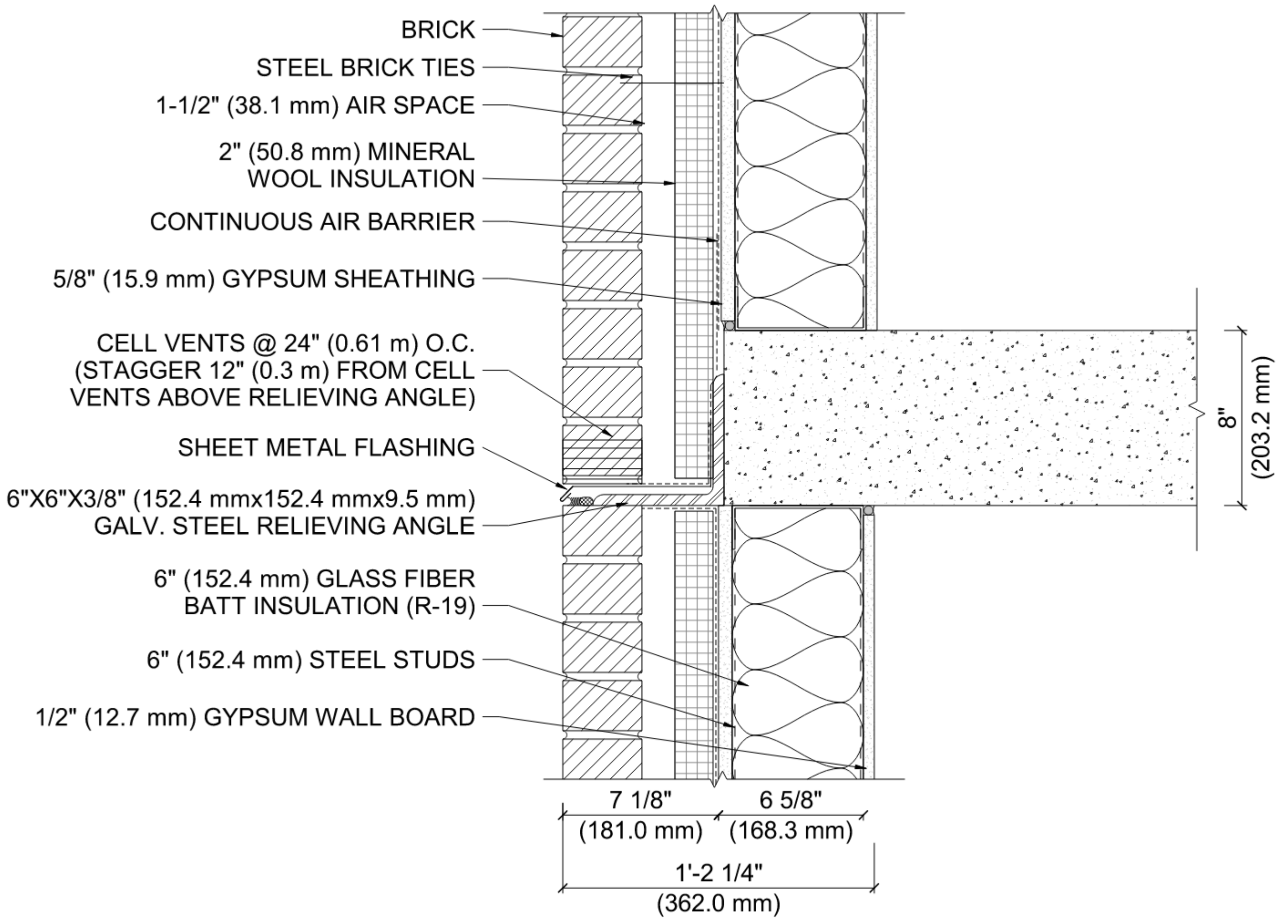
- 2023 MA Stretch Energy Code (alternative path for residential and commercial), and Municipal Opt-In Specialized Code (mandatory for large multifamily)
- 2022 Denver & Boulder (alternative path for residential and commercial)
- 2020 NYStretch (alternative path for 1 and 2 family dwellings)
- 2018 WA (alternative path for single family residential)

Presentation Outline

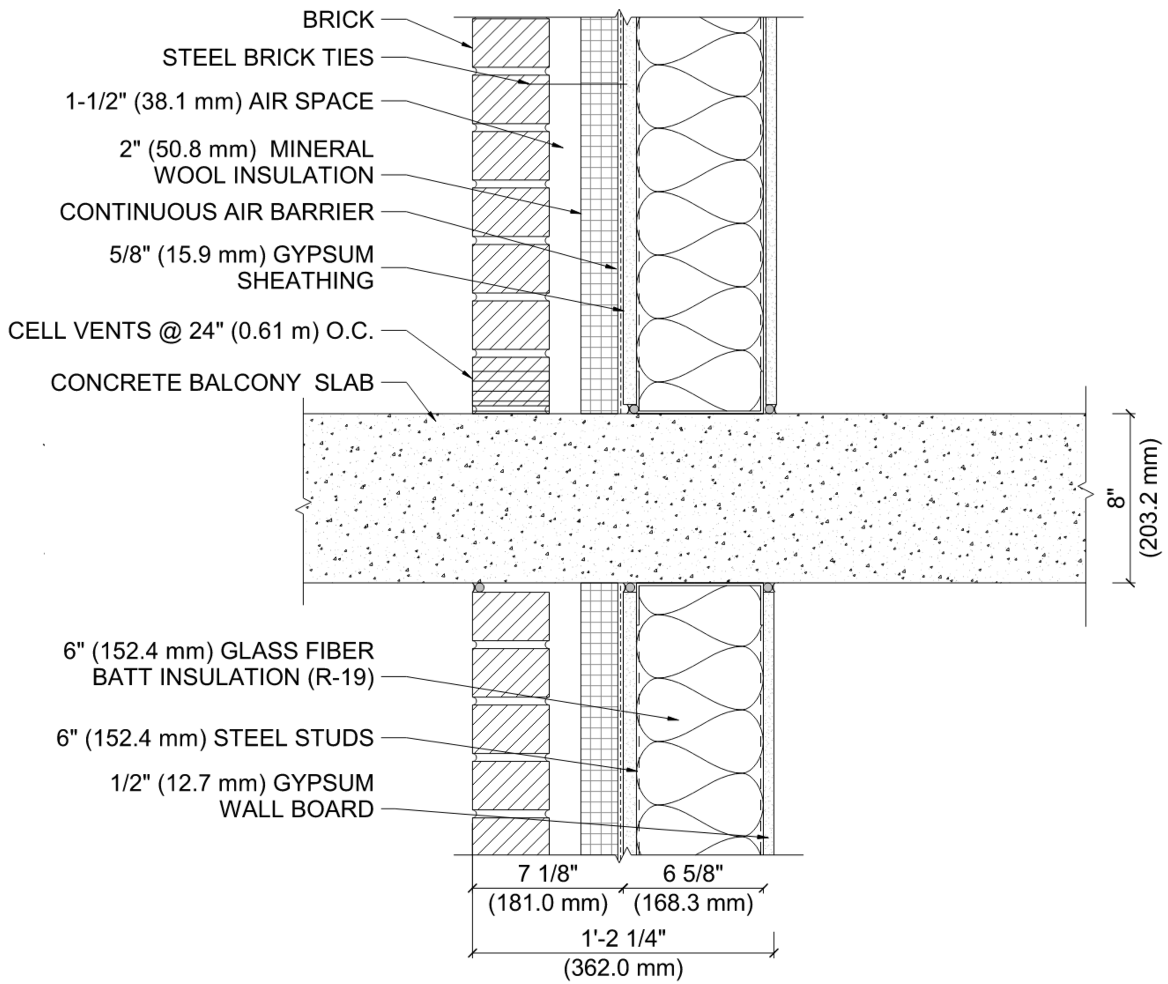
How do designers quantify and account for thermal bridges in the enclosure?

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies: Calculation Methods and Results
- MA Stretch Energy Code & PHIUS
- Conclusions, Implications, and Future Use

SGH



(a) Floor slab edge relieving angle



(b) Balcony slab penetration

Default Values & Manual Calculation Methods

- 2023 MA – Ψ per Table C402.6

Table C402.7.3.1 Linear Thermal Bridge Prescriptive PSI values.

Type of Linear Thermal Bridge	PSI-value (Btu/hr - ft – F)
Balcony to exterior vertical wall intersection	1.00 ←
Intermediate floor to exterior vertical wall intersection	0.60
Interior vertical wall to exterior vertical wall intersection	0.50
Fenestration to exterior vertical wall intersection	0.32
Parapet (vertical wall to roof intersection)	0.60
Brick shelf angle	0.35 ←
Vertical wall to grade intersection	0.52
Vertical wall plane transition (building corners and other changes in vertical wall plane)	0.25

- ASHRAE 90.1-2022– per Table A10.1

Table A10.1 Thermal Bridging Psi-Factors and Chi-Factors for Thermal Bridges

			Unmitigated		Default	
Class of Construction—Wall, above Grade	Thermal Bridge Type	Section	Psi-Factor, Btu/(h·ft·°F)	Chi-Factor, Btu/(h·°F)	Psi-Factor, Btu/(h·ft·°F)	Chi-Factor, Btu/(h·°F)
Steel framed and *metal buildings*	*Roof* edge	5.5.5.1.1	0.450	N/A	0.140	N/A
	Parapet	5.5.5.1.2	0.289		0.151	
	Intermediate floor to *wall* intersection	5.5.5.2.1	0.487		0.177	
	Intermediate floor balcony or overhang to opaque *wall* intersection	5.5.5.2.2	0.487		0.177 ←	
	Intermediate floor balcony in contact with *vertical fenestration*	5.5.5.2.2	0.974		0.177	
	Cladding support	5.5.5.3	0.314		0.217 ←	
	Wall to *vertical fenestration* intersection	5.5.5.4	0.262		0.112	
	Other element and assembly intersections	5.5.5.5	N/A	1.73	N/A	0.91

SGH

Default Values & Manual Calculation Methods

- 2020 NYCECC – Ψ per Table C402.6

TABLE C402.6
AVERAGE THERMAL TRANSMITTANCE FOR UNMITIGATED LINEAR THERMAL BRIDGES

TYPE OF THERMAL BRIDGE	Ψ-value[a] [Btu/hr • ft • F]
Balcony	0.50 ←
Floor Slab	0.44
Fenestration Perimeter Transition[b]	0.32
Parapet	0.42
Shelf Angle	0.41 ←

a. Psi-values are derived from the *BC Hydro Building Envelope Thermal Bridging Guide Version 1.2 - September 2018*, and are based on poor performing details.

b. Fenestration Perimeter Transition is the thermal bridge between any fenestration frame and the typical wall, roof or floor assembly it abuts or is mounted within.

- 2017 DCECC – Calculated per Section 5.4.1.1 Option B – Simplified Approach

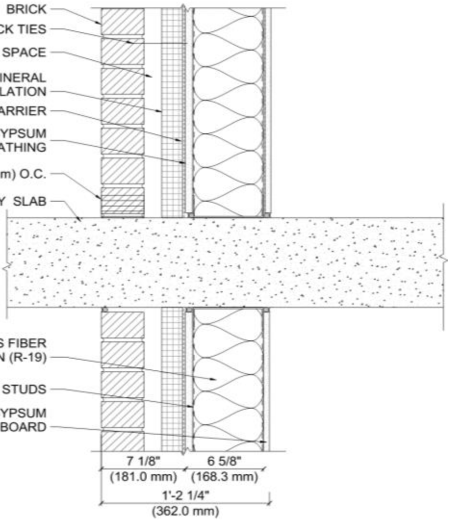
Option B – Simplified Approach:

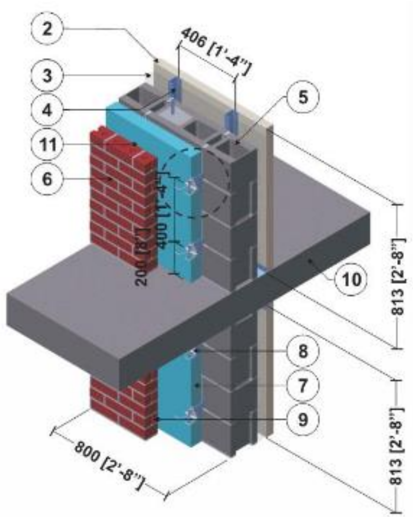
1) Find the lowest Default Linear Anomaly for Vertical Assembly applicable to the proposed design. Use this value to include in Equation 5.4.1.1. ← Wall Anomaly Coefficient (Wac), per Table 5.4.1.1(2)
2) Determine the Default Cladding Attachment Coefficient for the proposed design. ← Cladding Attachment Coefficient (Cac), per Table 5.4.1.1(1)
3) Use Equation 5.4.1.1 to determine U-value$_{(Overall\ including\ Thermal\ Bridges)}$ for vertical walls.
4) Use the calculated U-value$_{(Overall\ including\ Thermal\ Bridges)}$ for compliance with prescriptive U-value compliance per Table 5.5, Trade off method Section 5.6 (via COMCheck), or the proposed energy model via Appendix G.
5) Calculations and assumptions shall be presented to the authority having jurisdiction.

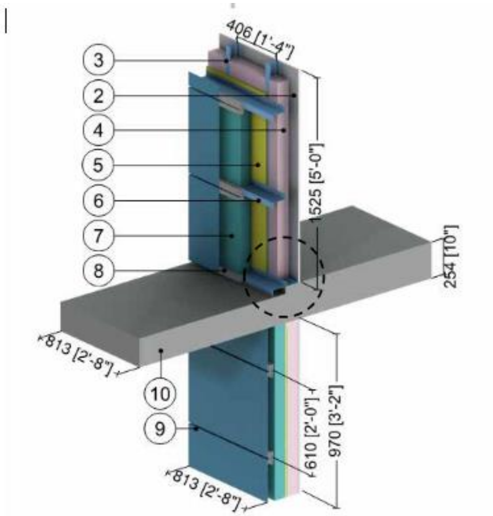
Default Values & Manual Calculation Methods

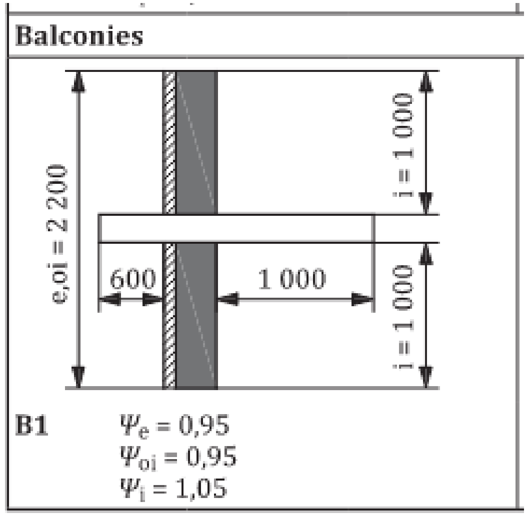
Source	(a) Floor slab edge relieving angle	(b) Balcony slab penetration
2023 MA Stretch	0.350	1.000
2020 NYCECC	0.410	0.500
2017 DC	0.228	0.056
ASHRAE 90.1-2022	0.217	0.177

Thermal Bridge Catalogues





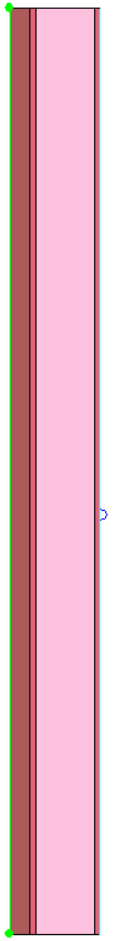




Source	ASHRAE RP-1365 – Detail 38	BETB Guide – Detail 5.2.5	ISO 14683 – Case B1, external dimensions
Thermal Bridge Configuration	Balcony slab projecting through continuous R-15 exterior cavity insulation	Balcony slab projecting through continuous R-15 exterior cavity insulation	Slab edge projection through a wall assemb with continuous exterior wall insulation abov and below the slab edge
Cladding Type/ Attachment	Brick masonry veneer with metal brick ties	Metal Panel with horizontal z-girts	
Backup Construction	CMU with 1-5/8 in. steel furring (uninsulated)	4 in. nominal cold-formed metal framing with R-12 batt insulation within the stud cavity	

Numerical Calculation Methods

Clear Field



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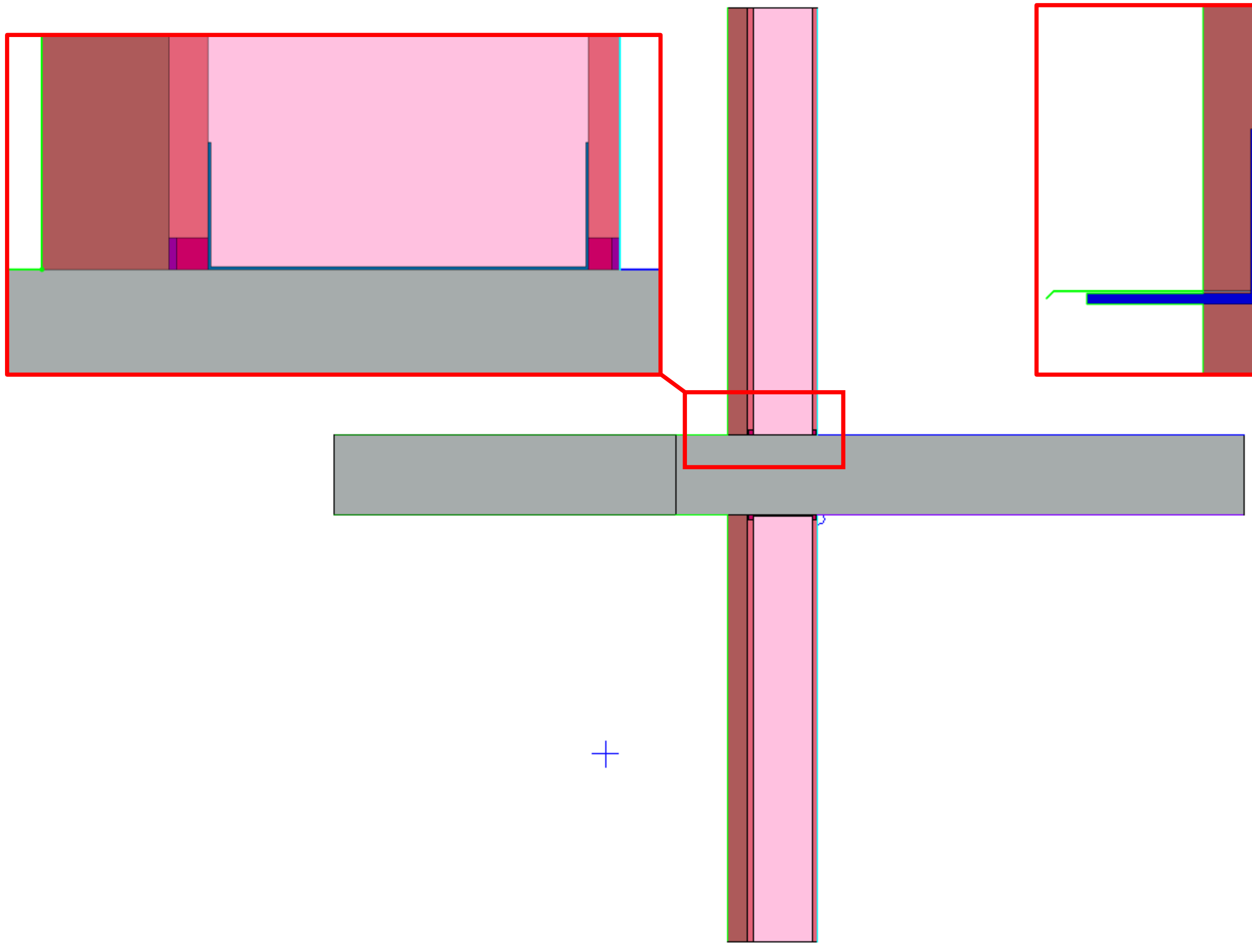
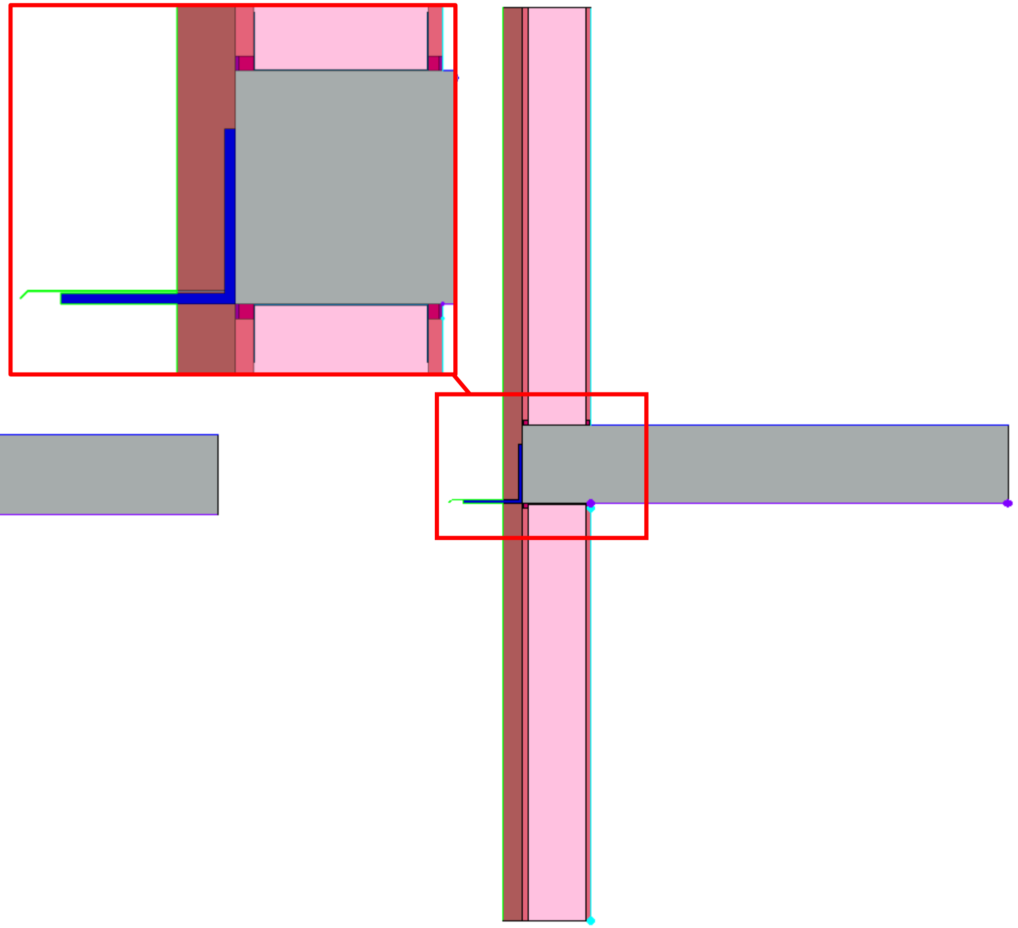
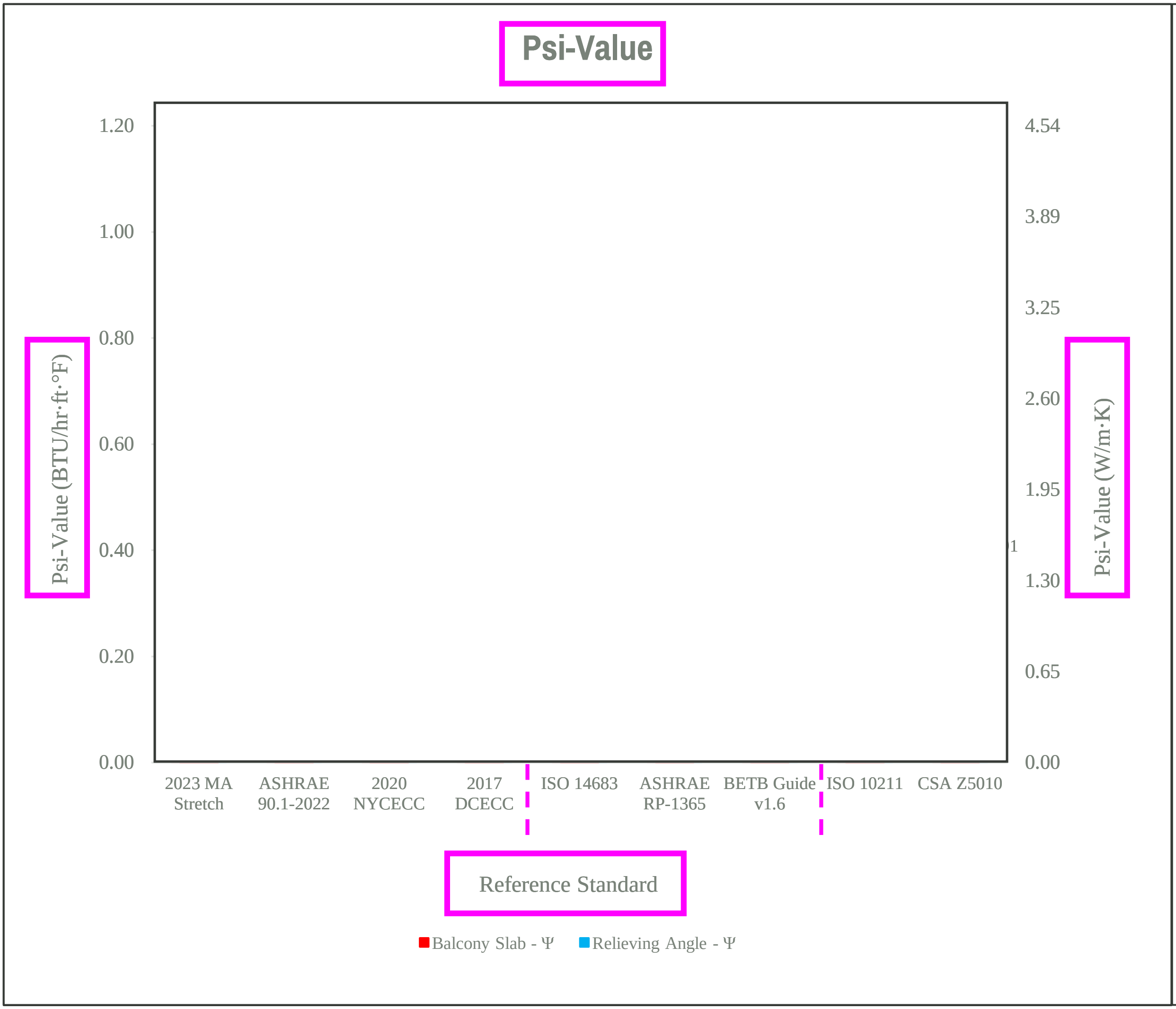
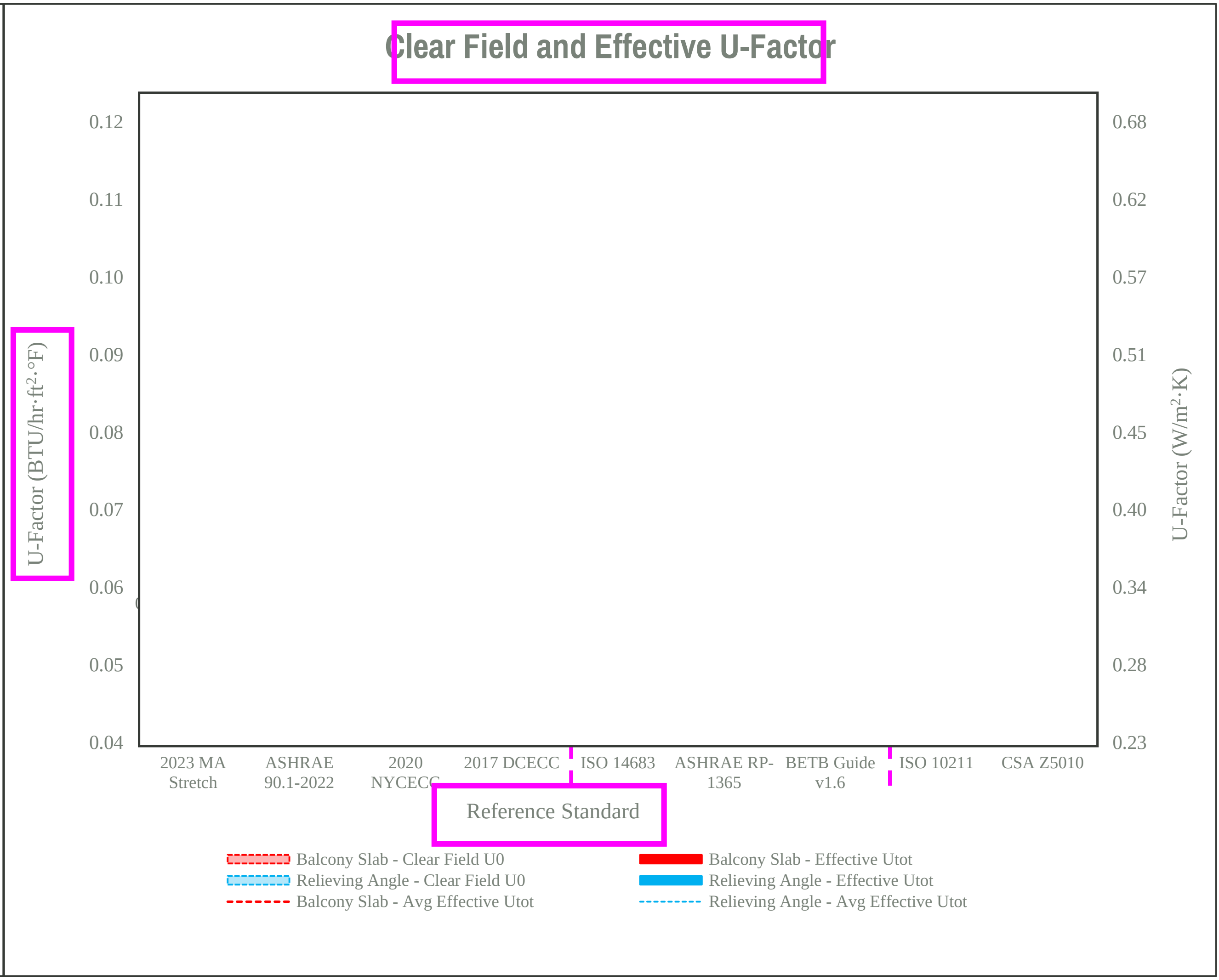


(b) Balcony slab penetration

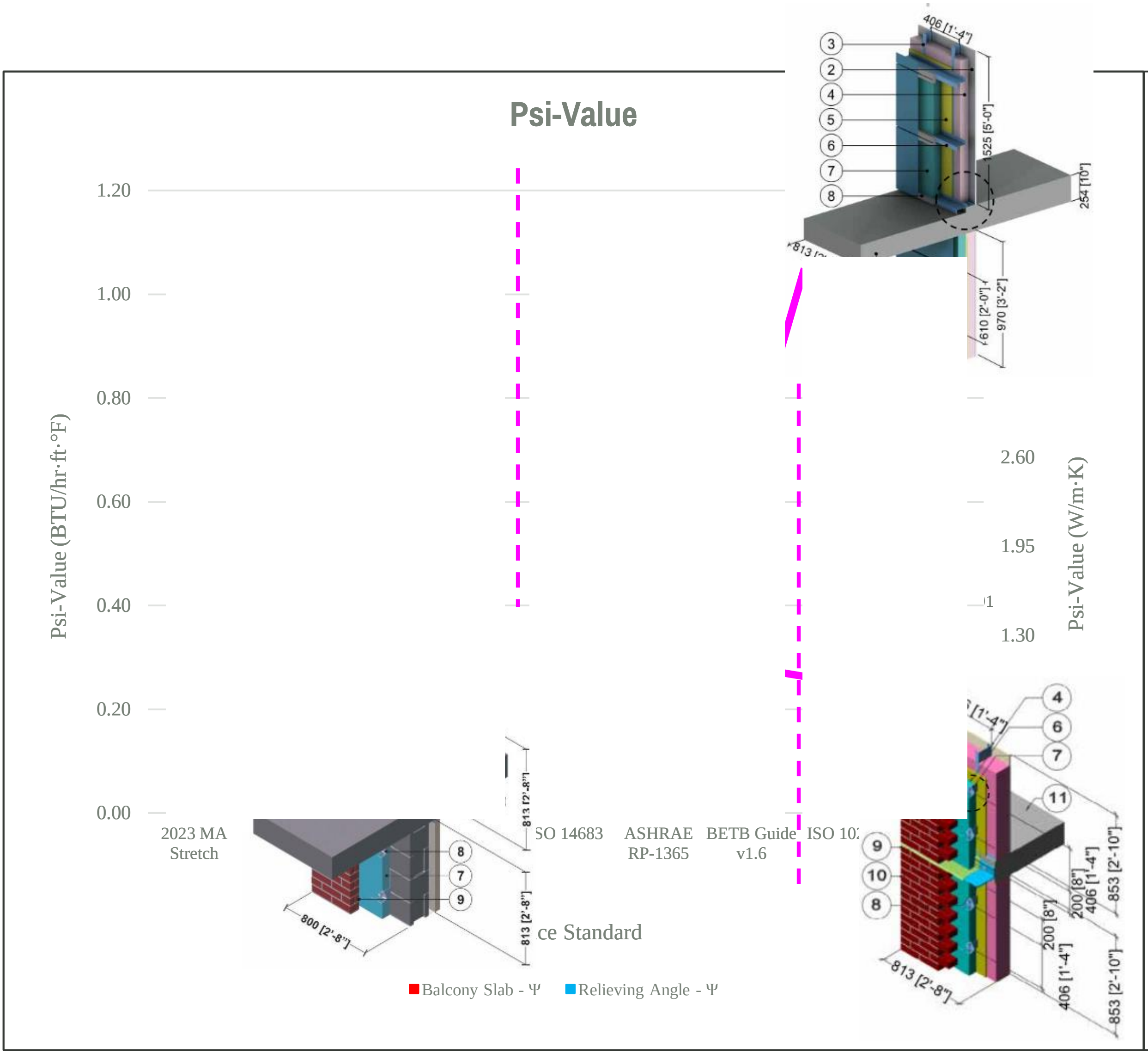


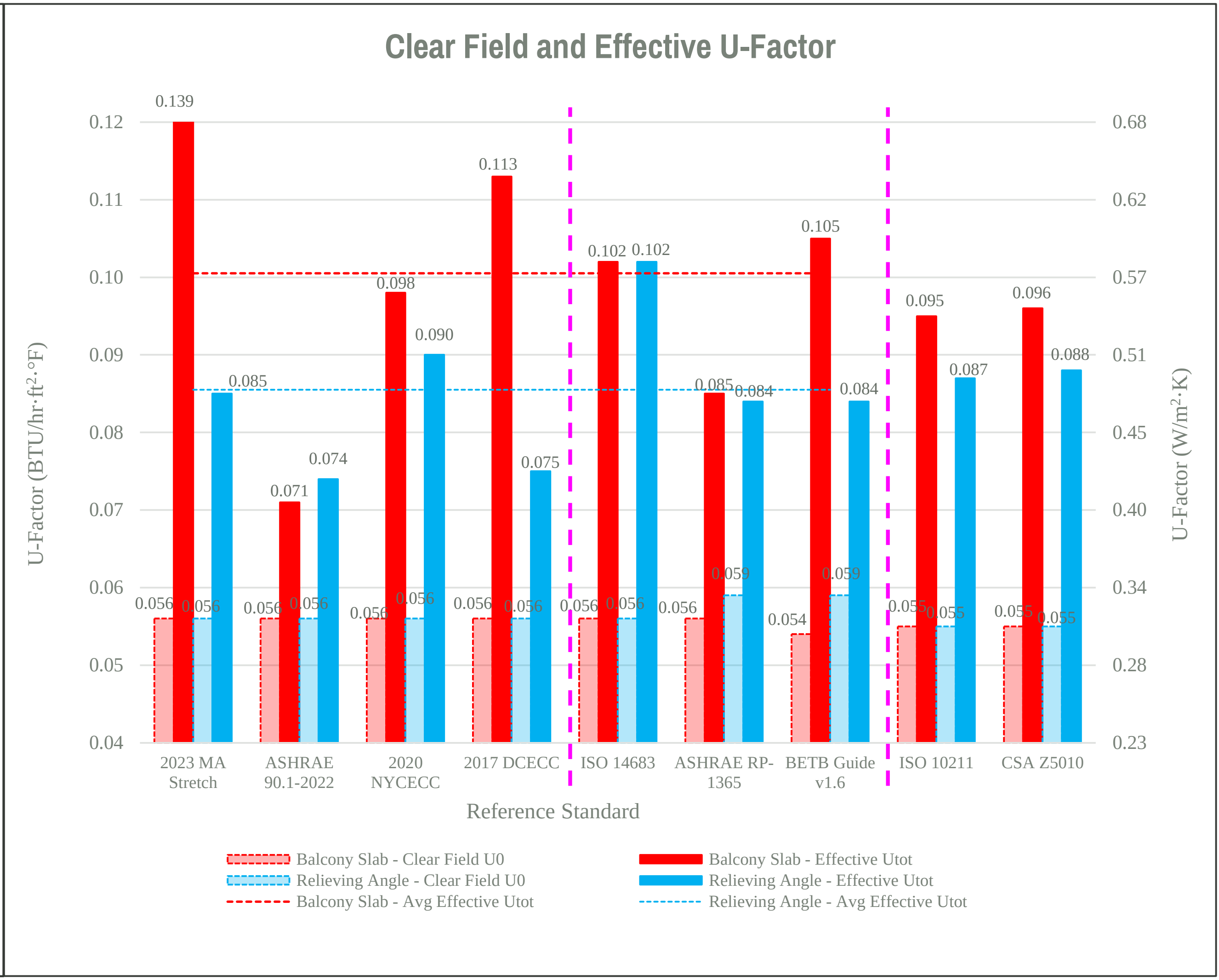
Case Studies | Summary of results





Case Studies | Summary of results





Key Takeaways

- **Detail similarity –** Differences in results of the selected case studies are primarily due to the project-specific assembly and catalogue geometry. Cladding type and attachment and backup construction can significantly impact results.

- **Relative Impact –** The thermal transmittance (Ψ- or χ- factor) generally correlate with the overall assembly thermal transmittance (U-factor), but the effect is diluted or magnified by the quantity of a given thermal bridge condition that actually occurs on a building-wide scale (i.e., length or number in relation to envelope area).

Presentation Outline

What does this mean for individual buildings?

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies: Calculation Methods and Results
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Other Required Derating

Continuous Insulation for Vertical Walls

- Prescriptive Derating

$R_{derated} = R_o \times Derating\ Factor$

Where

$$Derating\ Factor = \begin{Bmatrix} 0.7, & \text{if brick veneer} \\ 0.74 - 0.021 \times R_o, & \text{if } R_o \leq R - 15 \\ 0.55 - 0.007 \times R_o, & \text{if } R_o > R - 15 \\ 0.8, & \text{if qualifying thermal break} \end{Bmatrix}$$

- Reference Derating
- Modelled Derating

Linear Thermal Bridges

$$U_{derated} = \frac{\Psi * Length}{A_{total}} + U_o$$

where Ψ is determined from

- Prescriptive Derating
- Reference Derating
- Modelled Derating

Thermal Resistance of Spandrel Sections

R-value is determined from

- Prescriptive R-value
- Reference R-value
- Modelled R-value

Thermal Bridges Influence Building Envelope Compliance

Use derated values when showing compliance with

- **Prescriptive Compliance** – maximum U-factors for envelope assemblies and components

- **Component Performance Alternative** – above grade vertical wall and fenestration areas

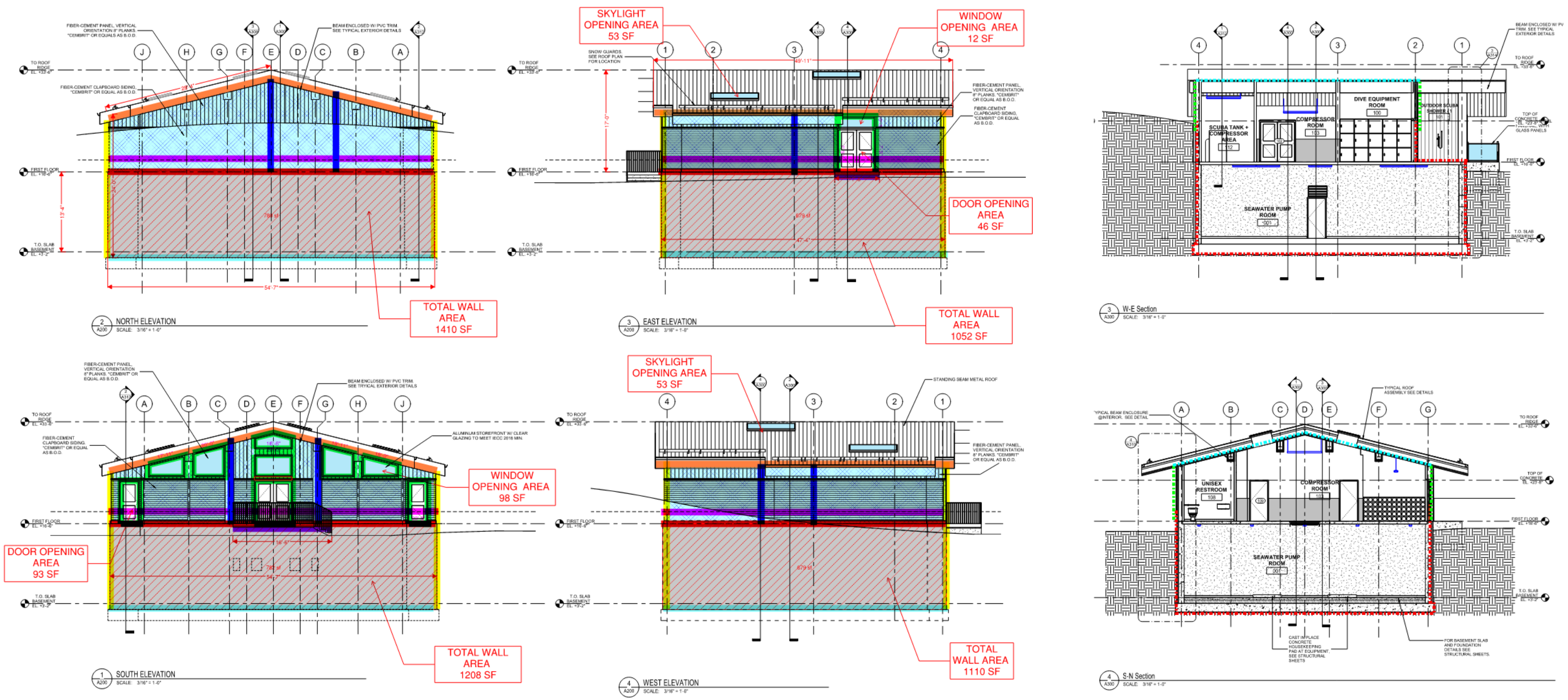
$$\text{Area} - \text{weighted U proposed} = \begin{Bmatrix} \leq 0.1285, & \text{if } \leq 50\% \; \textit{glazed wall system} \\ \leq 0.1600, & \text{if } > 50\% \; \textit{glazed wall system} \end{Bmatrix}$$

and vision glass used in the *glazed wall system* shall have a maximum whole assembly U factor of U-0.25

2023 MA Stretch Energy Code – NON-PHIUS Project

Component Performance Alternative

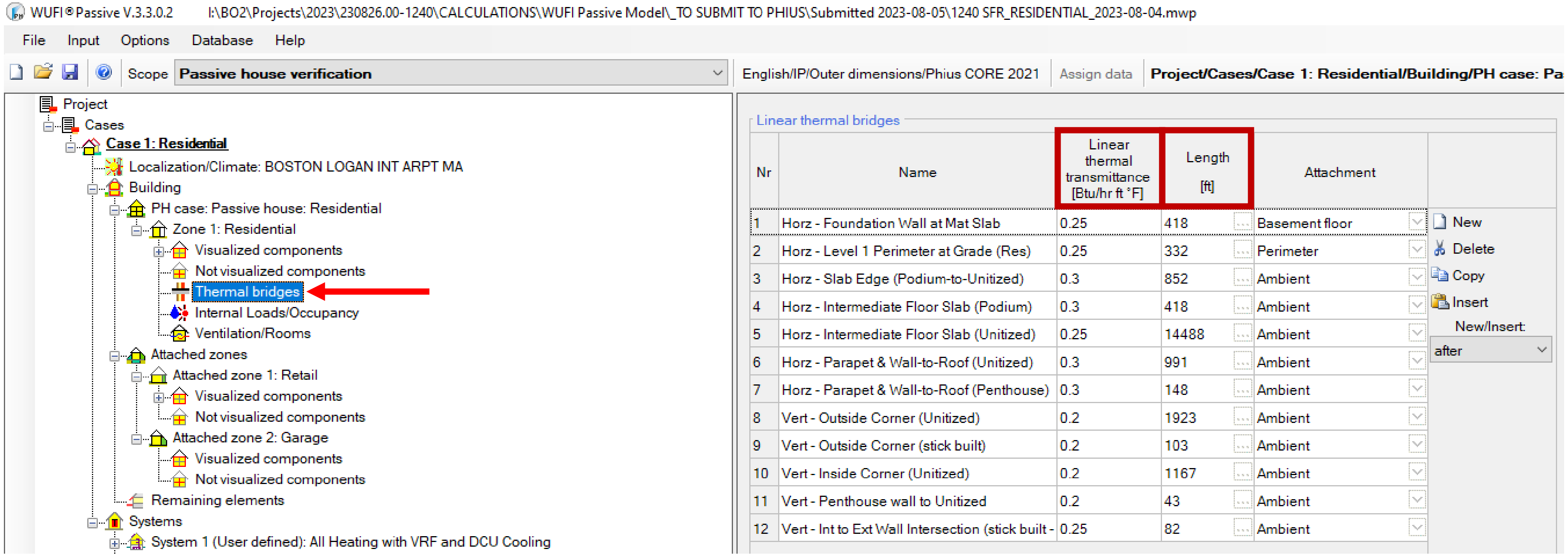
ENCLOSURE THERMAL BRIDGE IDENTIFICATION



$$U_{derated} = \frac{\Psi * Length}{A_{Total}} + U_0$$

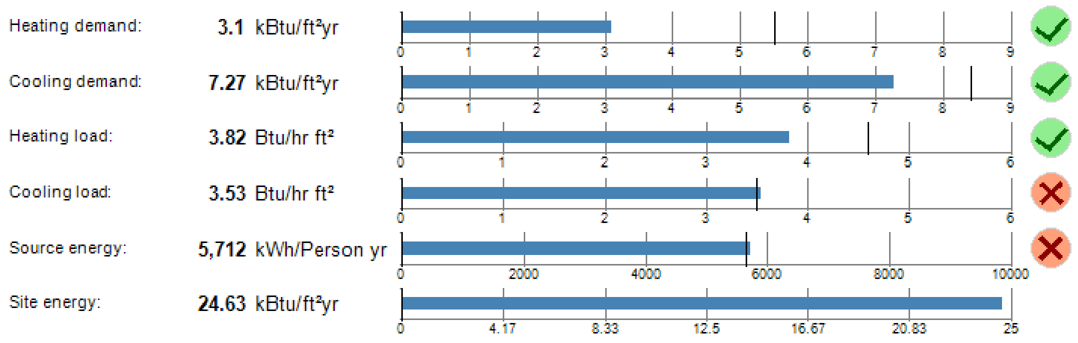
OVERALL WEIGHTED AVERAGE U-VALUES		
Overall	0.1285	Max. Permitted U
	0.1262	Proposed U
	2%	% Improvement over code

PHIUS – Thermal Bridges in WUFI Passive



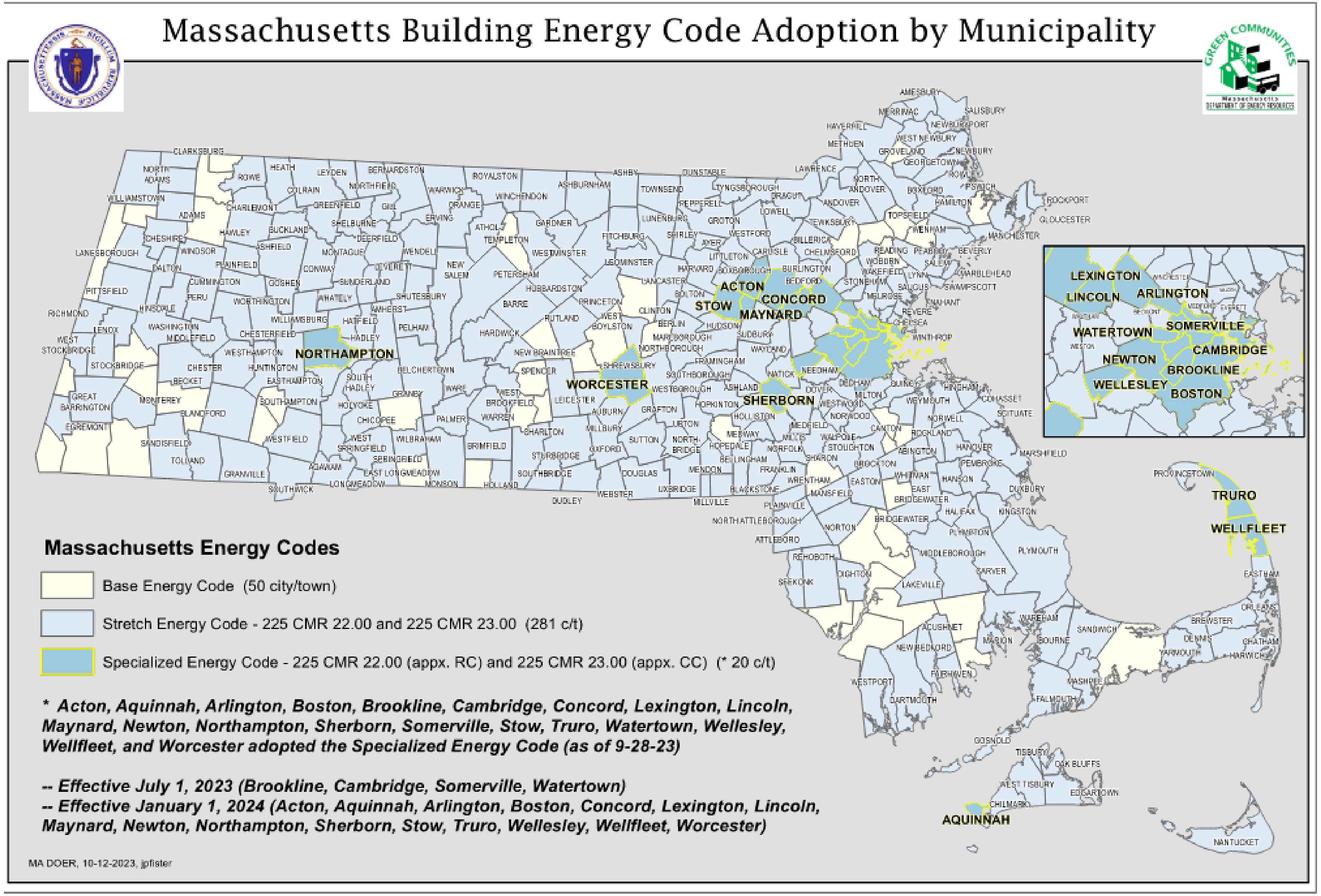
Nr	Name	Linear thermal transmittance [Btu/hr ft °F]	Length [ft]	Attachment
1	Horz - Foundation Wall at Mat Slab	0.25	418	Basement floor
2	Horz - Level 1 Perimeter at Grade (Res)	0.25	332	Perimeter
3	Horz - Slab Edge (Podium-to-Unitized)	0.3	852	Ambient
4	Horz - Intermediate Floor Slab (Podium)	0.3	418	Ambient
5	Horz - Intermediate Floor Slab (Unitized)	0.25	14488	Ambient
6	Horz - Parapet & Wall-to-Roof (Unitized)	0.3	991	Ambient
7	Horz - Parapet & Wall-to-Roof (Penthouse)	0.3	148	Ambient
8	Vert - Outside Corner (Unitized)	0.2	1923	Ambient
9	Vert - Outside Corner (stick built)	0.2	103	Ambient
10	Vert - Inside Corner (Unitized)	0.2	1167	Ambient
11	Vert - Penthouse wall to Unitized	0.2	43	Ambient
12	Vert - Int to Ext Wall Intersection (stick built -	0.25	82	Ambient

Manual entry of transmittance (BTU/hr-ft-F) and Length (ft)



PHIUS Performance Criteria

PHIUS/PHI as a code compliance path



Massachusetts

Stretch Energy Code

- Alternate compliance path
  - Commercial - Certified Performance Standard Compliance
  - Residential – Passive House Building Certification Option

Municipal Opt-In Specialized Code

- R-use buildings (or portions of mixed-use buildings) over 12,000 sf
  - ≤5 stories – Passive House required from January 1, 2023
  - 6+ stories – Passive House required from January 1, 2024

Comparing Thermal bridge requirements

2023 MA Stretch Energy Code

- Compliance based on effective envelope performance values
- Limitations
  - Vertical envelope assemblies only
  - Not all thermal bridges included

PHIUS

- Thermal bridges area evaluated based on
  - Impact on building energy consumption
  - Comfort and condensation risk criteria
- Interaction between envelope, mechanical systems, and project environment

Presentation Outline

How do the Methods Compare?

Should we standardize requirements to account for thermal bridges?

- Thermal Bridges Overview
- Industry Codes, Standards, and Guidelines
- Case Studies:
- Calculation Methods and Results
- MA Stretch Energy Code & PHIUS
- → Conclusions, Implications, and Future Use

Considering Thermal Bridges for Project Performance

- **Methodology Selection & Accuracy –**
  - Precalculated values are not clearly more conservative compared to project specific calculations.
  - Selecting the appropriate method mostly depends on jurisdiction, certifications, and owner/project requirements. Consider accuracy of catalogue vs. project specific detail and length/repetition for impact to thermal transmittance

- **Impact to project –** For buildings with repetitive thermal bridges, the difference in the accounting method and its results can have a significant compounded effect on predicted thermal transmittance.

Design Professionals Navigating Requirements

- **Designer's Dilemma –** Representative details are often not available in catalogues. Calculations take time and resources – both should be focused on details that are most impactful to the project, beyond what is required by code.

- **Code Landscape** – Knowledge and experience required for multiple methods, guidance for selecting code compliance path across project types.

Designers continue to face the question – "Is modeling required?"

- Reliant on engineering judgment to interpret and correctly select from available resources.
- Even atypical conditions should be reviewed for their condensation potential and potential impact to occupant comfort.

Standardize Thermal Bridging Methodology

- Nationalized standard for reporting, analyzing, and accounting for thermal bridges, and standardized calculation method.
- ASHRAE 90.1 requiring accounting for thermal bridging forces jurisdictions who adopt ASHRAE to require it.

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Questions?

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