**Committee Generated Thermal Bridging Proposal**

**Replacement of CEPI-33, -40, and -45**

Draft 4/12/2022 – Version 19

**Proponents:**

Jay Crandell, ABTG/ARES Consulting, representing the Foam Sheathing Committee of the American Chemistry Council

Stéphane Hoffman, Morrison Hershfield

Jonathan Humble, American Iron and Steel Institute

Ivan Lee, Morrison Hershfield

Helen Sanders, Technoform North America, representing the Façade Tectonics Institute

Theresa Weston, Holt Weston Consultancy, representing the Rainscreen Association of North America (RAiNA)

Paula Zimin, Steven Winter Associates

*Add new construction documentation requirement to section C103.2:*

**C103.2 Information on construction documents.**

…Details shall include, but are not limited to, the following as applicable:

1. Energy compliance path.
2. Insulation materials and the R-values.
3. Fenestration U-factors and solar heat gain coefficients (SHGCs).
4. Area-weighted U-factor and solar heat gain coefficients (SHGCs).
5. Mechanical system design criteria.
6. Mechanical and service water-heating systems and equipment types, sizes and efficiencies.
7. Economizer description.
8. Equipment and system controls.
9. Fan motor horsepower (hp) and controls.
10. Duct sealing, duct and pipe insulation and location.
11. Lighting fixture schedule with wattage and control narrative.
12. Location of daylight zones on floor plans.
13. Air barrier and air sealing details, including the location of the air barrier.
14. *Thermal bridges* as identified in Section C402.6.

*Revise and add new definitions as follows:*

**SECTION C202**

**DEFINITIONS**

***F-*FACTOR.** The perimeter heat loss factor per unit perimeter length of ~~for~~ slab-on-grade floors (Btu/h x ft x oF) [W/(m x 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 x ft x oF)[W/(m x K)].

***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 oF) [W/K].

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

*Revise as follows:*

**SECTION C402**

**BUILDING ENVELOPE REQUIREMENTS**

**C402.1 General.** *Building thermal envelope* assemblies for buildings that are intended to comply with the code on a prescriptive basis in accordance with the compliance path described in Item 1 of Section C401.2.1 shall comply with the following:

1. The opaque portions of the *building thermal envelope* shall comply with the specific insulation requirements of Section C402.2 and the thermal requirements of either the *R-*value-based method of Section C402.1.3; the *U-*, *C-* and *F-*factor-based method of Section C402.1.4; or the component performance alternative of Section C402.1.5.
2. Roof solar reflectance and thermal emittance shall comply with Section C402.3.
3. Fenestration in building envelope assemblies shall comply with Section C402.4.
4. Air leakage of building envelope assemblies shall comply with Section C402.5.
5. *Thermal bridges* in *above-grade walls* shall comply with Section C402.6.

*Add new section as follows:*

**C402.6 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-in/h-ft2-F that includes blocking, coping, flashing, and other similar materials for attachment of roof and wall coverings.
3. *Thermal bridges* accounted for in the *U-factor* or *C-factor* for a *building thermal envelope*.

**C402.6.1 Balconies and floor decks.** Balconies and concrete floor decksshall 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 includes a *U*-factor of 0.8 Btu/hr-F-ft2 for the area of the *above-grade wall* penetrated by the concrete floor deck, or
	2. an *approved* thermal break device of not less than R-10 is installed in accordance with the manufacturer’s instructions and aligned with one of the insulation components within the *building thermal envelope*.

**C402.6.2 Cladding supports.**  Cladding support elements shall be off-set from the structure with attachments that allow the full-thickness of *continuous insulation,* where present, to pass behind the cladding support element.

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

**C402.6.3 Structural Beams and columns.** Structural steel and concrete beams and columns that penetrate the *building thermal envelope* shall be encapsulated on all exposed sides with not less than R-5 insulation for a distance of not less than 2-feet beyond the interior or exterior surface of an insulation component on or within the *building thermal envelope*.

**Exceptions:**

1. An *approved* thermal break device installed in accordance with the manufacturer’s instructions and aligned with one of the insulation components within the *building thermal envelope*.
2. An *approved* design where the *above-grade wall* *U*-*factor* used to demonstrate compliance accounts for the beam or column *thermal bridge*.

**C402.6.4 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 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 with a wood buck that is not less than 1.5 inch 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 a*pproved* design for the *above-grade wall* *U-factor* used for compliance accounts for *thermal bridges* at the intersection with the vertical fenestration.
2. Doors

**C402.6.5 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 to the top.
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 shall be extended a minimum of 2 feet 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 abut at the roof-ceiling-wall intersection.

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

*Revise Section C402.1.5 as follows:*

**C402.1.5 Component performance alternative.** Building envelope and fenestration areas determined in accordance with Equation 4-2 shall be an alternative to compliance with the *U-*, *F-, psi-, chi-,* and *C*-factors in Tables C402.1.4, C402.1.5, and C402.4 and the maximum allowable fenestration areas in Section C402.4.1. Fenestration shall meet the applicable SHGC requirements of Section C402.4.3

A + B + C + D + E + T ≤ Zero

Where:

…

T = Sum of the (ψL Dif) and (χN Dif) values for each type of *thermal bridge* condition of the *building thermal envelope* as identified in Section C402.6. For the purposes of this section, the ψL Dif and χN Dif values for *thermal bridges* caused by materials with a thermal conductivity less than or equal to 3.0 Btu-in/h-ft2-F shall be assigned as zero. For buildings or structures located in Climate Zones 0 through 3, the value of T shall be assigned as zero.

ψL Dif = ψL Proposed – ψL Table.

ψL Proposed = Proposed *psi-factor* × length of the *thermal bridge* elements in the proposed *building thermal envelope*.

ψL Table = (*psi-factor* specified as “compliant” in Table C402.1.5) × length of the *thermal bridge* linear elements.

χN Dif = χN Proposed – χN Table.

χN Proposed = Proposed *chi-factor* x number of the *thermal bridge* point elements other than fasteners, ties, or brackets in the proposed *building thermal envelope*.

χN Table = (*chi*-*factor* specified as “compliant” in Table C402.1.5) x number of the *thermal bridge* point elements.

A proposed *psi-* or *chi-factor* for each *thermal bridge* shall comply with one of the following as applicable:

1. Where the proposed mitigation of a *thermal bridge* is compliant with the requirements of Section C402.6, the “compliant” values in Table C402.1.5 shall be used for the proposed *psi*- or *chi*-*factors*.
2. Where a *thermal bridge* is not mitigated in a manner at least equivalent to Section C402.6, the “non-compliant” values in Table C402.1.5 shall be used for the proposed *psi*- or *chi*-*factors*.
3. Where the proposed mitigation of a *thermal bridge* provides a *psi-* or *chi-factor* less than the “compliant” values in Table C402.1.5, the proposed *psi*- or *chi*-*factor* shall be determined by thermal analysis, testing, or other *approved* sources.

**TABLE C402.1.5**

***PSI*- AND *CHI*-*FACTORS* TO DETERMINE THERMAL BRIDGES**

**FOR THE COMPONENT PERFORMANCE ALTERNATIVE**

|  |  |  |
| --- | --- | --- |
| **Thermal Bridge per Section C402.6** | **Thermal Bridge** **Compliant with Section C402.6** | **Thermal Bridge****Non-Compliant with Section C402.6** |
| **psi-factor****(Btu/h-ft-oF)** | **chi-factor****(Btu/h-oF)** | **psi-factor****(Btu/h-ft-oF)** | **chi-factor****(Btu/h-oF)** |
| C402.6.1 Balconies, slabs, and decks | 0.2 | n/a | 0.5 | n/a |
| C402.6.2 Cladding supports | 0.2 | n/a | 0.3 | n/a |
| C402.6.3 Structural beams and columns | n/a | 1.0 – carbon steel0.3 – concrete | n/a | 2.0 – carbon steel1.0 - concrete |
| C402.6.4 Vertical fenestration | 0.15 | n/a | 0.3 | n/a |
| C402.6.5 Parapets | 0.2 | n/a | 0.4 | n/a |

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

n/a = not applicable

*Revise Table C407.4.1(1) as follows:*

Portions of table not shown are unchanged

**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 C402.1.4 | As proposed |
| *Thermal bridges*: Account for heat transfer consistent with “compliant” *psi-* and *chi*-*factors* from Table C402.1.5 for *thermal bridges* as identified in Section C402.6 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 C402.1.5.  |
| Solar absorptance: 0.75 | As proposed |
| Emittance: 0.90 | As proposed |

**REASON:** As requested by the sub-committee,this proposal is a combination of CEPI-33, 40, 45 which now provides prescriptive, component performance alternative and total building performance compliance paths and a requirement to note thermal bridges on the construction documents. It combines the best of the individual proposals, plus improvements and modifications provided by the subcommittee and other interested parties. It also adds language for the component performance alternative compliance path, which was not present in the individual proposals.

The key rationale for specifying the minimum performance of thermal bridges at key interfaces is that currently they are ignored in the IECC, which therefore assumes no thermal performance degradation at assembly interfaces and penetrations of the building thermal envelope.

Ignoring thermal bridges at interfaces leads us to believe that our building thermal envelopes perform much better than they do, and to the widely recognized performance gap between as-designed/code compliant design and as-built [1]. According to the Building Envelope Thermal Bridging Guide created by Morrison Hershfield for BC Housing [2], thermal bridging can reduce the thermal performance of the opaque building envelope by between 20-70%. Non-thermally broken cladding attachments can degrade the thermal performance of opaque panel assemblies by 50% [2]. Morrison Hershfield have also found that 13% of the heat loss through a typical steel stud wall with punched opening windows is due to the window to wall transition and they found it to be even higher with poorer edge details. This is a huge degradation in performance that the code is currently ignoring and must be addressed to improve the energy performance of as-built structures.

Also, in the 2021 IECC, the definition for above-grade wall (shown below) was changed in a way that supports a need to address thermal bridging at intersections of above-grade walls with floors, roofs, and fenestration, which were previously ignored.

"WALL, ABOVE-GRADE. A wall associated with the building thermal envelope that is more than 15 percent above grade and is on the exterior of the building or any wall that is associated with the building thermal envelope that is not on the exterior of the building. **This includes, but is not limited to, between-floor spandrels, peripheral edges of floors, roof knee walls, dormer walls, gable end walls, walls enclosing a mansard roof and skylight shafts."**[bold added for emphasis]

In order to achieve net-zero performance we need to address these significant energy losses through thermal bridges at the building thermal envelope. This proposal seeks to take a small step towards recognizing and accounting for thermal bridges that are typically present in conventional construction. It seeks to recognize and account for current design and construction practices, not to drive a large change in construction practices. The proponents believe that this is a good first step to move building thermal envelope performance and to get the design and construction industry thinking about thermal bridges in the design process.

**Inclusion in construction documents**

The inclusion of thermal bridge details on construction documents will encourage design teams to identify and address thermal bridging. The requirements for what thermal bridges to identify on the construction documents is referenced to section C402.6 where the types of thermal bridges are identified. This will ensure that only the main thermal bridges need be shown. A definition for thermal bridges is also proposed to support the proposal.

**Definitions**

New definitions psi-factor and chi-factor are introduced to describe linear and point thermal bridges in the *building thermal envelope* in a similar way to the existing F-factor for heat loss for slab-on-grade floors. These definitions are used in the component performance alternative and the performance compliance paths. We have chosen to call them psi and chi-factors as this is how they are commonly referred to, and we wanted to avoid confusion.

A new definition for thermal bridges is included and incorporates comments from the subcommittee.

**Prescriptive path**

In the prescriptive path, we have taken the route of CEPI-33 in creating a simple yet flexible approach, focusing on a few thermal bridge conditions that have the most impact, and which have practical and available means to effectively manage the bridging. In every case, alternative means and methods are permitted with an approved design to avoid any unnecessary restriction or inflexibility. The proponents feel that this is an appropriately abbreviated and enforceable way to address this topic in the energy code.

The goal was to create a simple, prescriptive, effective, and flexible means to begin to address and reasonably mitigate the effects of major thermal bridges which are now identified in the new definition (IECC 2021) for above-grade walls. To inform the proposed prescriptive requirements, various thermal bridging studies, detailing guides, and provisions developed domestically and internationally were reviewed [2-7].

**Component performance alternative**

In this section the linear and point thermal bridges (psi-, chi- factors) are included in the formula in a similar way to the existing U-, F- and C- factors. A table of psi- and chi-factors are provided to be used in this section, for the five prescriptive categories of thermal bridges. There are values proposed for thermal bridges compliant or non-compliant with the prescriptive path. The values provided for thermal bridges compliant with the prescriptive path are reflective of those details (which are not very stringent). The values provided for non-compliant are reflective of poorer interface details. The psi- and chi-factors of thermal bridges which exceed the prescriptive requirement are permitted to be determined by thermal analysis, testing or other approved sources.

Including values of thermal bridging in this section will ensure that any trade-offs in between envelope assemblies will account for thermal bridging.

Note that this section will need to be rationalized with CEPI-46 which addresses a problem with the current component performance alternative equation, if both are accepted by the committee.

**Performance path**

The performance path language ensures that the reference design accounts for thermal bridging rather than assuming no thermal bridges exist and that the interfaces are “perfect”. This allows for good thermal bridging details in the proposed design to show improved energy performance.

The reference design uses the psi- and chi-factors from the component performance alternative section for those thermal bridges which are present in the proposed design. The proposed building uses psi- and chi- factors for thermal bridges calculated according to the methods allowed in the component performance alternative.

**Bibliography**

[1] https://en.wikipedia.org/wiki/Performance gap

[2] BC Housing, Thermal Bridging Guide, Version 1.5, 2020, https://www.bchousing.org/research-centre/library/residential-design-construction/building-envelope-thermal-bridging-guide

[3] Morrison Hershfield Ltd. (2011)

[4] ASHRAE 1365-RP Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc

[5] ISO Standard 14683: 2007, Thermal Bridges in Building Construction – Linear thermal transmittance (simplified methods and default Chi-factors).

[6] AISC/SEI, Thermal Bridging Solutions: Minimizing Structural Steel’s Impact on Building Envelope Energy Transfer, A Supplement to Modern Steel Construction, March 2012, American Institute for Steel Construction (AISC) & Structural Engineering Institute (SEI).

[7] USACE, “Development of Thermal Bridging Factors for Use in Energy Models,” ERDC/CERL TR-15-10, June 2015, U.S. Army Corp of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory.

**COST IMPACT:**

The code change proposal will neither increase nor decrease the cost of construction.

There should be no change in construction cost as this proposal enforces the intent of code and closes the gap between what is being built today and what code intends to be built.

In effect, perfect mitigation or no thermal bridging at interfaces is implied by code. Current practice is to ignore them or provide no or little mitigation. This proposal provides a way of practical mitigation which does not require significant changes to current practices. Practical mitigation can be considered a first cost reduction relative to perfect mitigation, which would cost more to achieve than is currently proposed.

From another perspective, this practical mitigation may be viewed as a first cost increase relative to common practice, which does not meet the perfect performance implied by the existing code nor the relatively low performance bar proposed here. However, by quantifying the impact of thermal bridges we provide the option to address them in each compliance path which helps mitigate costs.

**Note to staff:** The above language for section **C402.1.5 Component performance alternative** is appropriate to the current equation in this section. But this is what it would look like if the current modification to CEPI-46 passes (**text in** **orange from this proposal** would be added to the CEPI-46 proposed modified **language in blue**):

AP + BP + CP + TP ≤ AT + BT + CT + TT – VF – VS  **(Equation 4-2)**

wher**e:**

AP = Sum of the (area x U-factor) for each proposed building thermal envelope assembly, other than slab-on-grade or below-grade wall assemblies

BP = Sum of the (length x F-factor) for each proposed slab-on-grade edge condition

CP = Sum of the (area x C-factor) for each proposed below-grade wall assembly

TP = Sum of the (ψLP) and (χNP) values for each type of *thermal bridge* condition of the *building thermal envelope* as identified in Section C402.6 in the proposed building. For the purposes of this section, the (ψLP) and (χNP) values for *thermal bridges* caused by materials with a thermal conductivity less than or equal to 3.0 Btu-in/h-ft2-F shall be assigned as zero. For buildings or structures located in Climate Zones 0 through 3, the value of TP shall be assigned as zero.

ψLP= *psi-factor* × length of the *thermal bridge* elements in the proposed *building thermal envelope*.

χNP = *chi-factor* x number of the *thermal bridge* point elements other than fasteners, ties, or brackets in the proposed *building thermal envelope*.

AT = Sum of the (area x U-factor permitted by Tables C402.1.4 and C402.4) for each proposed building thermal envelope assembly, other than slab-on-grade or below-grade wall assemblies

BT = Sum of the (length x F-factor permitted by Table C402.1.4 for each proposed slab-on-grade edge condition

CT = Sum of the (area x C-factor permitted by Table C402.1.4) for each proposed below-grade wall assembly

TT = Sum of the (ψLT) and (χNT) values for each type of *thermal bridge* condition in the proposed *building thermal envelope* as identified in Section C402.6 with values specified as “compliant” in Table C402.1.5. For the purposes of this section, the (ψLT) and (χNT) values for *thermal bridges* caused by materials with a thermal conductivity less than or equal to 3.0 Btu-in/h-ft2-F shall be assigned as zero. For buildings or structures located in Climate Zones 0 through 3, the value of TT shall be assigned as zero.

ψLT= (*psi-factor* specified as “compliant” in Table C402.1.5) × length of the *thermal bridge* elements in the proposed *building thermal envelope*.

χNT = (*chi-factor* specified as “compliant” in Table C402.1.5) x number of the *thermal bridge* point elements other than fasteners, ties, or brackets in the proposed *building thermal envelope*.

PF = Maximum vertical fenestration area allowable by Section C402.4.1, C402.4.1.1, or C402.4.1.2

QF = Proposed vertical fenestration area

RF = QF – PF, but not less than zero (excess vertical fenestration area)

SF = Area-weighted average U-factor permitted by Table C402.4 of all vertical fenestration assemblies

TF = Area-weighted average U-factor permitted by Table C402.1.4 of all exterior opaque wall assemblies

UF = SF – TF (excess U-factor for excess vertical fenestration area)

VF = RF x UF (excess UxA due to excess vertical fenestration area)

PS = Maximum skylight area allowable by Section C402.1.4

QS = Actual skylight area

RS = QS – PS, but not less than zero (excess skylight area)

SS = Area-weighted average U-factor permitted by Table C402.4 of all skylights

TS = Area-weighted average U-factor permitted by Table C402.4.1 of all opaque roof assemblies

US = SS – TS (excess U-factor for excess skylight area)

VS = RS x US (excess UxA due to excess skylight area)

A proposed *psi-* or *chi-factor* for each *thermal bridge* shall comply with one of the following as applicable:

1. Where the proposed mitigation of a *thermal bridge* is compliant with the requirements of Section C402.6, the “compliant” values in Table C402.1.5 shall be used for the proposed *psi*- or *chi*-*factors*.
2. Where a *thermal bridge* is not mitigated in a manner at least equivalent to Section C402.6, the “non-compliant” values in Table C402.1.5 shall be used for the proposed *psi*- or *chi*-*factors*.
3. Where the proposed mitigation of a *thermal bridge* provides a *psi-* or *chi-factor* less than the “compliant” values in Table C402.1.5, the proposed *psi*- or *chi*-*factor* shall be determined by thermal analysis, testing, or other *approved* sources.