FOREWORD

This work was initiated following the publication of ASHRAE Research Project 1365 “Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings”. The research report found that unaccounted heat flow through the cumulative impact of thermal bridges can increase the annual energy consumption associated with the building envelope when compared to a building without thermal bridges.

To help mitigate this impact, this addendum introduces requirements to address thermal bridges in this standard. The contents of this proposal include prescriptive and performance (e.g. modeling thermal transmission values) options. The goal is to provide users with as many options as are currently available and allow users to choose which method of evaluation (e.g. simple or complex) that may be in the best interest of the building owner or building project without sacrificing the existing stringency.

Further work that influenced this proposal included the BC Hydro “Building Envelope Thermal Bridging Guide” (which expands upon ASHRAE Research Project 1365 by Morrison-Hershfield), and ISO 14683 “Thermal bridges in building construction – Linear thermal transmittance – Simplified methods and default values.”

While the core requirements are in Section 5 (Prescriptive), several other sections are affected as the overall standard organization is respected.

- **Section 3 - Definitions**
  New definitions to support the proposal have been added.
- **Section 4 – Administration and Enforcement**
  Provisions for documenting pertinent data and features of thermal bridging details on construction documents
- **Section 5 - Building Envelope**
  These are the core prescriptive provisions
- **Section 11 – Energy Cost Budget**
  Directions for modeling both the budget building Design and proposed designs are located here
- **Section 12 – References**
  References added
- **Normative Appendix A**
  Baseline and prescriptive, psi, chi factors and assumptions are outlined here.
This proposal will improve the energy efficiency of buildings by addressing thermal bridges not currently regulated by the Standard.

The options shown were considered cost effective based on the methodology agreed to by the SSPC 90.1 committee, except for the large elements in which case an allowance is provided. Remember, the current standard assumes a near perfect building with no large elements passing thru the thermal envelope. This proposal, therefore offers the user two options, construct a near perfect wall, or take advantage of the allowances.

The proposal is focused on overcoming the complexities of predicting and mitigating thermal bridges. While there remains a wider assortment of specific details, this Addendum represents the introduction of some of the more common types of thermal bridges and mitigations. It is not a totally comprehensive list of thermal bridges in all structures.

As part of this 2nd Public Review, some text was added that modifies portions of the 2019 standard, those sub-sections are noted. All other strike thru and underline are to the 2016 standard.

[Note to Reviewers: This public review draft makes proposed independent substantive changes to the previous public review draft. These changes are indicated in the text by underlining (for additions) and strikethrough.
Addendum av to 90.1-2016

Revise Section 3.2 as follows:

**clear field thermal bridge:** See thermal bridge

**linear thermal bridge:** See thermal bridge

**point thermal bridge:** See thermal bridge

**chi-factor (χ or Chi):** thermal transmittance of a point thermal bridge in units of Btu/(h·°F) [W/K]

**cross section area of point load connections:** the area of individual load bearing elements connecting exterior building components to the primary structure whereby the area is measured in the plane of the insulation where the load bearing element penetrates the outer surface of the outermost layer of insulation.

**psi-factor (ψ or Psi):** thermal transmittance per unit length of a linear thermal bridge in units of Btu/(h·ft·°F) [W/(m·K)]

**thermal bridge:** An element that has higher thermal conductivity than the surrounding materials, which creates a path of least resistance for heat transfer. For the purposes of determining building envelope applications requirements, the classifications for thermal bridges are categorized defined as follows:

**clear field thermal bridge:** an area-based thermal transmission associated with elements of a building envelope assembly that are distributed over the area of the assembly and addressed in determining the thermal performance of the assembly in accordance with Normative Appendix A. Examples of clear field thermal bridges include studs, webs and face shells of masonry units, and ties, tracks, plates, girts and purlins for metal building envelopes, and fasteners. Fasteners used to construct assemblies in accordance with normative Appendix A are not considered nor separately defined as point thermal bridges.

**linear thermal bridge:** a length-based thermal transmission element associated with horizontal, vertical, or diagonal elements that penetrates the insulation in or construction details within the building envelope and with length measured along the exterior surface of the building envelope. Examples of linear thermal bridges include slab edges of floors, balconies, columns and beams in the plane of an assembly, parapets, other roof-wall-floor intersections, fenestration interfaces, shelf angles and similar conditions not otherwise addressed defined as a clear field thermal bridge or point thermal bridge.

**point thermal bridge:** an element-based thermal transmission associated with a discrete element that penetrates the insulation in the building envelope. Examples of point thermal bridges include three way corners, a beam penetrating a wall, a column penetrating a roof or floor, and an anchor or connection used to attach an element to the building and not otherwise addressed defined as a clear field thermal bridge or linear thermal bridge. The cross-sectional area of the point thermal bridge shall be measured at the outer surface of the outermost layer of insulation that is penetrated by the element.
Second Public Review Draft – Independent Substantive Changes

Revise 3.3 as follows:

### 3.3 Abbreviations and Acronyms

- **χ**  
  Chi-factor, thermal transmittance of a point thermal bridge
- **L**  
  Length of a linear thermal bridge
- **min.**  
  Minimum
- **n**  
  The number of occurrences a point thermal bridge
- **Ψ**  
  Psi-factor, thermal transmittance per unit length of a linear thermal bridge

Revise Section 4.2.2.1 (of the 2019 standard) as follows:

#### 4.2.2 Compliance Documentation

##### 4.2.2.1 Construction Details

Compliance documents shall show all the pertinent data and features of the building, equipment, and systems in sufficient detail indicating the location, nature and extent of the work proposed to permit a determination of compliance by the building official and to indicate compliance with the requirements of this standard.

Revise Section 5.5.3.2 as follows:

#### 5.5.3.2 Above-Grade Wall Insulation

All above-grade walls shall comply with the insulation values specified in Tables 5.5-0 through 5.5-8.

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**Exception to 5.5.3.2**

Alternatively, for mass walls, where the requirement in Tables 5.5-0 through 5.5-8 is for a maximum assembly U-0.151 (U-0.857) followed by footnote “b,” concrete masonry unit (CMU) walls complying with ASTM C90, that are ungrouted or partially grouted at 32 in. (800 mm) or greater on center vertically and 48 in. (1200 mm) or greater on center horizontally, shall have their ungrouted openings (e.g., cores, cells) filled with insulating material having a maximum thermal conductivity of 0.44 Btu·in/ h·ft²·°F (0.063 W/(m·K)).

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Add new Section 5.5.5 as follows:

#### 5.5.5 Linear Thermal Bridges and Point Thermal Bridges

To the extent that linear thermal bridges and point thermal bridges exist at locations on the building envelope, occur as described in Sections 5.5.5.1 through 5.5.5.5, they shall comply with the requirements of either:

a. Comply with the applicable requirements of Sections 5.5.5.1 through 5.5.5.5 or
b. Not exceed the mitigated Psi-factors and Chi-factors in Table A10.1, where the Psi-factors and Chi-factors for the thermal bridges are determined in accordance with Appendix A, Section A10, Section 5.5.5.6, provided that the total length of all balconies or floor overhangs does not exceed the maximum allowed in...
Section 5.5.5.2. Exception 2(c)(i) and the remaining intermediate floor-wall intersections have insulation having a rated R-value of insulation of R-5 (R-0.9).

For the purposes of 5.5.5, linear elements that are connected to the building structure by a series of point connections shall be permitted to be characterized as linear thermal bridges or as individual point thermal bridges. Alternatives to individual requirements required in Sections 5.5.5.1 through 5.5.5.5 shall be permitted provided that the Psi-factors and Chi-factors for the thermal bridges are determined to be in accordance with Appendix A, Section A10 and the values do not exceed those in Table A10.1.

Details for linear thermal bridges and point thermal bridges shall be clearly identified or otherwise noted on construction documents.

Exceptions to 5.5.5:
1. Buildings located in Climate Zone 4-0 through 3.
2. Semi-heated spaces in buildings located in Climate Zones 4-0 through 6.
3. Clear field thermal bridges.
4. Thermal bridges in Uninsulated assemblies.
5. Thermal bridges that have a material thermal conductivity less than 3.0 Btu·in/ h·ft²·°F(0.433 W/(m·K)).
6. Alterations to existing buildings in accordance with Section 5.1.3.

5.5.5.1 Roof and Wall Intersections. Where a roof with insulation entirely above deck intersects an exterior wall, the intersection shall comply with Sections 5.5.5.1.1, 5.5.5.1.2 and 5.5.5.1.3, as applicable, the roof insulation shall extend without interruption to at least the exterior face of the wall insulation or the wall insulation shall extend without interruption to the top of the roof insulation.

Informative Notes
See Figures 5.5.5.1a and 5.5.5.1b in Informative Appendix I.

Exceptions to 5.5.5.1:
One or more of the following exceptions shall be permitted:

- Blocking shall be permitted to interrupt insulation only for securement of any of the following to the building structure: roof covering, coping, and/or flashing materials.

5.5.5.1.1 Roof edges. At roof edges without parapets or overhangs, the roof insulation and the wall insulation shall comply with the following, as applicable to the location of the insulation:

- a. Where a wall has exterior continuous insulation, the roof insulation shall extend to the exterior of the wall insulation and the wall insulation shall extend to the roof insulation;
- b. Where a wall has cavity, or integral insulation, that represents more than 50 percent of the total wall insulation R-value, the cavity or integral insulation shall extend to the underside of the roof deck and the roof insulation shall extend to exterior face of the wall. The wall insulation shall be permitted to be interrupted by roof framing members and wall top plates or tracks.
- c. Where a mass wall with has interior insulation that represents more than 50 percent of the total wall insulation R-value, on the interior the insulation on the interior surface the wall shall extend to the underside of the roof deck, shall be permitted to be interrupted by framing members, and shall comply with one of the following:
Additional insulation having a rated R-value of insulation not less than R-5 (R-0.9) shall extend inward on the underside of the roof deck for not less than a minimum of 2 ft (0.6 m) and be permitted to be interrupted by roof framing members.

Additional insulation having a rated R-value of insulation not less than R-5 (R-0.9) shall be placed on the exterior of the wall to the depth of the roof assembly.

The wall insulation values in Tables 5.5-1 through 5.5-8 shall be adjusted in accordance with Table 5.5.5.1.2.

**Informative Note:**
See Figures 5.5.5.1.1a, 5.5.5.1.1b, 5.5.5.1.1c(i) and 5.5.5.1c(ii) in Informative Appendix J.

**5.5.5.1.2 Parapets:** At roof edges with parapets on roofs with insulation entirely above deck, the exterior interruption of the insulation is permitted under the following circumstances: wall insulation shall comply with one or any more combination of the following as applicable to the location of the insulation and wall assembly:

a. Any where a wall with has exterior continuous insulation, the exterior continuous such insulation shall be applied to both vertical sides of the parapet and to the top of the parapet.

**Informative Note:**
See Figure 5.5.5.1.2a Exception 4a in Informative Appendix J.

b. Any where a wall with has cavity insulation that represents more than 50 percent of the total wall insulation R-value, the cavity or integral the cavity insulation shall extend within the cavity of into the parapet at least to not less than the height of the top of the roof insulation.

**Informative Note:**
See Figure 5.5.5.1.2b Exception 4b in Informative Appendix J.

c. Any where a mass wall with has integral insulation that represents more than 50 percent of the total wall insulation R-value, the integral insulation shall extend to the coping at the top of the parapet below the coping and additional insulation having a rated R-value of insulation of not less than R-5 (R-0.9) minimum shall be placed on the roof side of the parapet and extending from the coping at the top of the parapet below the coping to at least not less than the top of the roof insulation below. Such integral insulation shall be permitted to be interrupted by framing members.

**Informative Note:**
See Figure 5.5.5.1.2c Exception 4c in Informative Appendix J.

d. Where a mass wall with has interior insulation that represents more than 50 percent of the total wall insulation R-value, on the interior side, the insulation on the interior surface of the wall shall extend to the underside of the roof deck, shall be permitted to be interrupted by framing members, and shall comply with one of the following:

i. Additional insulation having a rated R-value of insulation not less than R-5 (R-0.9) shall extend inward on the underside of the roof deck for not less than a minimum of 2 ft (0.6 m) and be permitted to be interrupted by roof framing members.

ii. Additional insulation having a rated R-value of insulation not less than R-5 (R-0.9)
shall be placed on the exterior of the wall to the depth of the roof assembly.

iii. The wall insulation values in Tables 5.5-1 through 5.5-8 shall be adjusted in accordance with Table 5.5.1.2.

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>R-Value Increase</th>
<th>U-factor % decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>R-1.0 (R-0.18)</td>
<td>8%</td>
</tr>
<tr>
<td>5</td>
<td>R-1.0 (R-0.18)</td>
<td>8%</td>
</tr>
<tr>
<td>6</td>
<td>R-1.5 (R-0.26)</td>
<td>10%</td>
</tr>
<tr>
<td>7</td>
<td>R-1.5 (R-0.26)</td>
<td>10%</td>
</tr>
<tr>
<td>8</td>
<td>R-2.5 (R-0.44)</td>
<td>14%</td>
</tr>
</tbody>
</table>

Informative Note:
See Figures 5.5.5.1.2d(i) and 5.5.5.1.2d(ii) Exception 4d in Informative Appendix I.

e. 5.5.5.1.3 Parapets within the field of a roof. Exterior continuous insulation having a minimum rated R-value of insulation of not less than R-5 (R-0.9) shall be applied to both vertical sides of the parapet and extend from the coping at the top of the parapet to not less than the top of the roof insulation below. Parapets that are an integral part of a fire wall, and the exterior continuous insulation applied to the parapet, shall be required to comply with the fire resistance ratings of the building code.

Informative Note:
See Figure 5.5.5.1.3 Exception 4e in Informative Appendix I.
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.

Informative Note:
Framed parapets should be constructed so that air does not flow from the indoor environment into the parapet cavity to minimize risk of condensation.

5. Roof overhangs on roofs with insulation entirely above deck, including the roof overhang, which comply with all of the following:

a. Any wall with exterior continuous insulation, the exterior continuous insulation shall extend to the underside of the roof deck and outward on the underside of the roof deck and overhang for a minimum of 2 ft (0.6 m) or to the end of the roof overhang when the overhang is less than 2 ft (0.6 m). Where the roof overhang is composed of cantilevered wood framing, the maximum total cross sectional area of the wood framing members penetrating the exterior continuous insulation shall not exceed 15 in.²/lin ft (32,000 mm²/lin m) and the continuous insulation shall extend upward between the wood roof framing members to the underside of the roof deck but shall not be required to be extended outward on the underside of the roof deck.

Informative Note:
See Figure 5.5.5.1 Exception 5a in Informative Appendix I.

b. Any wall with cavity insulation, the cavity insulation shall extend to the underside of the roof deck and shall be permitted to be interrupted by roof framing members and wall top plates or tracks.
Informative Note:
See Figure 5.5.5.1 Exception 5b in Informative Appendix I.

c. Any mass wall with integral insulation, in addition to the integral insulation, additional insulation having a rated R-value of insulation of R-5 (R-0.9) minimum shall be applied to the interior surfaces of the wall and roof deck and shall extend a minimum of 2 ft (0.6 m) along each surface as measured from the roof-wall intersection.

Informative Note:
See Figure 5.5.5.1 Exception 5c in Informative Appendix I.

d. Mass wall with insulation on the interior side, the insulation on the interior surface of the wall shall extend up to the underside of the roof deck and inward on the underside of the roof deck for a minimum of 2 ft (0.6 m).

Informative Note:
See Figure 5.5.5.1 Exception 5d in Informative Appendix I.

5.5.5.2 Walls and Intermediate Floor Intersections. At floor and exterior wall intersections, All the exterior wall insulation shall comply with Sections 5.5.5.2.1, 5.5.5.2.2, and 5.5.5.2.3 as applicable to the type of floor intersection, exterior wall assembly and location of the exterior wall insulation be extended across the intermediate floor edge and shall be contiguous between the wall below and wall above.

Informative Note:
See Figures 5.5.5.2a, 5.5.5.2b, and 5.5.5.2c in Informative Appendix I.

Exceptions to 5.5.5.2:

4. 5.5.5.2.1 Intermediate floor edges that do not serve as without balconies or floor overhangs which shall comply with all of the following as applicable:

a. Where a wall has exterior continuous insulation, such insulation shall extend continuously past the floor edge.

b. Any where a wall with has cavity insulation that represents more than 50 percent of the total wall insulation R-value, the cavity insulation shall extend to the underside of the floor deck and shall be permitted to be interrupted by floor framing members and wall top and bottom plates or tracks.

Informative Note:
See Figures 5.5.5.2.1b-1 and 5.5.5.2.1b-2 Exception 1a in Informative Appendix I.

c. Any where a mass wall with has integral insulation that represents more than 50 percent of the total wall insulation R-value, the intermediate floor intersection shall comply with one of the following:

i. The full thickness of integral insulation shall extend to the underside of past the floor edge, or deck and;

ii. Where the intermediate floor deck extends through the integral insulation, additional insulation having a minimum rated R-value of insulation of not less than R-5 (R-0.9) shall
be applied/maintained to the full depth of the floor edge on the exterior side of the floor edge wall and shall be permitted to be interrupted by structural connections.

**Informative Note:**
See Figures 5.5.5.2.1c-1 and 5.5.5.2c-2 Exception 1b in Informative Appendix IJ.

c. d. Where a mass wall with insulation that represents more than 50 percent of the total wall insulation R-value on the interior side, insulation on the interior side of the wall shall extend up to the underside of the floor deck and additional, shall be permitted to be interrupted by framing members, and shall comply with one of the following:

i. Additional insulation having a minimum rated R-value of insulation of not less than R-5 (R-0.9) shall be applied to cover the full depth of the floor edge. Such insulation shall be permitted to be interrupted by floor framing members. Fire safing applied to the full depth of the floor edge meets this requirement, at the interior face of the mass wall in alignment with insulation on the interior side of the wall, or

ii. Additional insulation having a rated R-value of insulation not less than R-5 (R-0.9) shall be applied to cover the full depth of the floor edge on the exterior side of the wall wall.

iii. The wall insulation values in Tables 5.5-1 through 5.5-8 shall be adjusted in accordance with Table 5.5.5.2.1.

**Informative Note:**
See Figures 5.5.5.2.1d(i) Exception 1c(i) and 5.5.5.2.1d(ii) Exception 1c(ii) in Informative Appendix IJ.

d. e. Where mass mass walls have not less than with a minimum of 50 percent of the rated R-value of insulation on the exterior side of the wall and the remainder on the interior side, the insulation on the interior side of the wall shall be permitted to be interrupted by the an intermediate floor.

**Informative Note:**
See Figure 5.5.5.2.1e Exception 1d in Informative Appendix IJ.

<table>
<thead>
<tr>
<th>Table 5.5.5.2.1 – Additional wall insulation required for mass walls with insulation on the interior at intersections with intermediate floor intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Zone</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
</tbody>
</table>

2. Intermediate floor edges with balconies and floor overhangs which comply with all of the following:

a. Where a balcony or floor overhang is supported by point load connections, the full depth of the cavity insulation, integral insulation, and exterior continuous insulation on any wall shall pass between the attached balcony or floor overhang and the interior floor deck or primary structure. The insulation shall be permitted to be penetrated by a cross sectional area of point load connections to the primary structure not exceeding:

i. 1.4 in²/lin ft (2800 mm²/lin m) of the intersection with the building envelope for carbon steel connectors, or
ii. 2.0 in.²/lin ft (4200 mm²/lin m) of the intersection with the building envelope for stainless steel connectors.

**Informative Note:**
See Figures 5.5.5.2 Exception 2a(i) and 5.5.5.2 Exception 2a(ii) in Informative Appendix I.

b. Where a balcony or floor overhang is separately supported from the building structure, requirements of Exception 2a above shall apply and the cross sectional area of point load connections to the primary structure shall not exceed one-half the amount permitted in Exception 2a.

**Informative Note:**
See Figure 5.5.5.2 Exception 2b in Informative Appendix I.

c. Where a balcony or floor overhang is not supported by point load connections and is not separately supported:

5.5.5.2.2 i. The total length of \( M_{\text{mass}} \) floor assembly projections serving as balconies or floor overhangs shall be permitted to that penetrate the building envelope for a maximum cumulative length along each story not exceeding the following percentages of the total building perimeter depicted in Table 5.5.5.2.2. For this calculation, total building perimeter is the sum of the perimeters of each above grade floor where it intersects the exterior building envelope.

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Maximum percent of building perimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>35%</td>
</tr>
<tr>
<td>5</td>
<td>30%</td>
</tr>
<tr>
<td>6</td>
<td>20%</td>
</tr>
<tr>
<td>7</td>
<td>10%</td>
</tr>
<tr>
<td>8</td>
<td>0%</td>
</tr>
</tbody>
</table>

Exceptions to 5.5.5.2.2
1. ii. Mass floor assembly projections located immediately directly above and providing protection to a pedestrian walkway at the street-level shall be permitted without the limits specified in item i above.
2. Mass floor assembly projections thermally broken with a thermal spacer block not less than R-12 (R-2.1). The thermal spacer block shall be permitted to be interrupted by structural connections.

d. Where the balcony or floor overhang is composed of cantilevered wood framing, the maximum total cross sectional area of the wood floor framing members shall not exceed 15 in.²/lin ft (32,000 mm²/lin m) of the intersection with the building envelope. The wall insulation shall extend upward between the wood floor framing members to the underside of the floor deck and any cavity insulation...
shall be permitted to be interrupted by wall top plates.

3. **5.5.5.3 Exterior Cladding Support.** Intermediate floor edges with shelf angles—shelf angles supporting steel that support masonry, exterior cladding shall be mounted away offset from the floor edge or primary structural frame using point load connections to accommodate the full depth of any exterior **continuous insulation** to pass between the support and floor or structure, exclusive of the point connections. The total cross-sectional area of the point load connections shall not exceed 1.5 in.\(^2\) /lin ft (3200 mm\(^2\)/lin m) of steel shelf angle for carbon steel connectors or 2.3 in.\(^2\) /lin ft (4900 mm\(^2\)/lin m) for stainless steel connectors. The attachments shall allow the full depth of any other cladding supports that penetrate the exterior **continuous insulation** shall be subject to the provisions of section 5.5.5.5 to pass behind the shelf angle, and be mounted away from the backup construction using point connections to accommodate the full depth of any exterior **continuous insulation** exclusive of the point connections.

**Exception to 5.5.5.3:**
Girts in metal building walls as described in Appendix A

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**Informative Note:**
See Figure 5.5.5.2 3 Exception 3 in Informative Appendix I.

**5.5.5.4 Opaque Wall and Vertical Fenestration Intersection.** **Vertical fenestration** shall be installed in accordance with one or more of the following as applicable:

a. Where **continuous insulation** is present, **vertical fenestration** the outermost glazing layer is aligned within the thickness of or within 2 in. of either face of the **continuous insulation** layer.

**Informative Note:**
See Figure 5.5.5.3a-4a in Informative Appendix I.

b. For **vertical fenestration**, where **continuous insulation** is not present, the outermost glazing layer is aligned within the thickness of the wall insulation layer and not more than 2 in. (50 mm) from the exterior side of the outermost insulation layer.

**Informative Note:**
See Figure 5.5.5.3b-4b in Informative Appendix I.

**Exceptions to 5.5.5.3:**

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2. d. Intersections between vertical fenestration and opaque spandrel in a common shared fenestration framing system that has a thermal break with a thermal conductivity of 3.6 Btu·in/h·ft²·°F (0.519 W/(m·K)) or less.

Exception to 5.5.5.4
3. Intersections between vertical fenestration and uninsulated opaque walls.

**Informative Note:**
See Figure 5.5.5.4c(i) in Informative Appendix J.

### 5.5.5.4 Shading Devices, Vertical Fins, and Awnings
All wall insulation shall be extended across and not be interrupted by shading devices, vertical fins, and awnings.

**Exception to 5.5.5.4:** Shading devices, vertical fins, and awnings shall be permitted to be supported by point load connections that pass through the cavity insulation, integral insulation, exterior continuous insulation, or insulation on the interior side of any wall. The maximum total cross sectional area of point load connections shall not exceed:

a. 0.7 in.²/lin ft (1400 mm²/lin m) of the element’s intersection with the building envelope for carbon steel connectors, or
b. 1.0 in.²/lin ft (2100 mm²/lin m) of the element’s intersection with the building envelope for stainless steel connectors.

**Informative Note:**
See Figure 5.5.5.4 in Informative Appendix I.

### 5.5.5.5 Other Elements and Building Assembly Intersections
Other individual point thermal bridges and linear thermal bridges not addressed in Sections 5.5.5.1 through 5.5.5.4 shall comply with equation 5.5.5.5 not pass through the above grade building envelope.

**Exceptions to 5.5.5.5:**

1. Building service openings
   Service penetrations, including mechanical, electrical, plumbing, telecommunications, and fire services that pass thru the opaque building envelope.

2. Clear field thermal bridges
   Insulated roof curbs and blocking.

3. Other individual Point thermal bridges that are less than the allowances in table 5.5.5.5, elements and fasteners having a maximum cross sectional area of 0.31 in² (200 mm²) and their associated washers, battens, or plates.

<table>
<thead>
<tr>
<th>Table 5.5.5.5 Allowable point thermal bridge cross sectional area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Area per point thermal bridge In² (mm²)</td>
</tr>
<tr>
<td>Common material name</td>
</tr>
<tr>
<td>3 (1935)</td>
</tr>
<tr>
<td>Carbon Steel</td>
</tr>
</tbody>
</table>
4. Other point thermal bridges and linear thermal bridges where the cross sectional area complies with Equation 5.5.5.5:

\[ 347 \text{ Btu} \cdot \text{in.}/(\text{ft}^2 \cdot \text{hr} \cdot \text{°F}) \times 0.0042\% \cdot \text{above grade area of the building envelope} \geq (k_1 \times A_1) + (k_2 \times A_2) + (k_3 \times A_3) \ldots \]  
(5.5.5.5) I-P

\[ 50 \text{ W}/(\text{m} \cdot \text{K}) \times 0.0042\% \cdot \text{above grade area of the building envelope} \geq (k_1 \times A_1) + (k_2 \times A_2) + (k_3 \times A_3) \ldots \]  
(5.5.5.5) S-I

Where

\[ k_1, k_2, k_3 \ldots = \] the thermal conductivity of material 1, material 2, material 3, etc… expressed in Btu \cdot \text{in.}/(\text{ft}^2 \cdot \text{hr} \cdot \text{°F}) (W/(m \cdot K)) for point thermal bridge material 1, material 2, material 3, etc… (such as, but not limited to e.g. concrete, carbon steel, stainless steel, wood)

\[ A_1, A_2, A_3, \ldots = \] the total cross sectional area of point thermal bridges and linear thermal bridges of material 1, material 2, material 3, etc….expressed in ft² (m²)

Informative Note:
See Appendix A, Chapter 26, or Chapter 33 in the ASHRAE handbook of fundamentals for typical material thermal conductivity.

5.5.5.6 Increased Insulation R-Value and Decreased Assembly and Fenestration U-Factor Alternate Compliance Path. As an alternate to complying with Sections 5.5.5.1 through 5.5.5.5 for individual thermal bridges, each class of construction of the entire above grade area of the building envelope shall comply with either:

a. Section 5.5.3a requirements for minimum cavity insulation and minimum continuous insulation with an increase in the minimum rated R-value of insulation for the continuous insulation and decrease in the vertical fenestration U-factor as specified in Table 5.5.5.6, or

b. Section 5.5.3b requirements for a maximum assembly U-factor with a decrease in the maximum assembly U-factors and vertical fenestration U-factors as specified in Table 5.5.5.6.

and Section 5.5.4 requirements for a maximum Vertical Fenestration assembly U-factor with a further decrease in the maximum assembly U-factor as specified in Table 5.5.5.6.

<table>
<thead>
<tr>
<th>9 (5800)</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 (41935)</td>
<td>Concrete and Masonry</td>
</tr>
</tbody>
</table>

Table 5.5.5.6 Increased Rated R-Value of Insulation and Decreased Assembly U-Factor for Opaque Roofs, Walls and Vertical Fenestration for each Class of Construction
### Table 5.5.5.6 Increased Rated R-Value of Insulation and Decreased Assembly U-Factor for Opaque Roofs, Walls and Vertical Fenestration for each Class of Construction

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Minimum Rated R-Value of Insulation</th>
<th>Maximum Assembly U-Factor</th>
<th>Fenestration U-Factor</th>
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<tbody>
<tr>
<td></td>
<td>Roofs</td>
<td>Walls</td>
<td>Roofs</td>
</tr>
<tr>
<td>4</td>
<td>Table 5.5-4 plus additional</td>
<td>R-3.7 e.i.</td>
<td>R-3.0 e.i.</td>
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<td>5</td>
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<td>R-3.7 e.i.</td>
<td>R-3.6 e.i.</td>
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<td>R-3.8 e.i.</td>
<td>R-4.8 e.i.</td>
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<tr>
<td>7</td>
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<td>R-5.3 e.i.</td>
<td>R-6.1 e.i.</td>
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<tr>
<td>8</td>
<td>Table 5.5-8 plus additional</td>
<td>R-5.3 e.i.</td>
<td>R-12.2 e.i.</td>
</tr>
</tbody>
</table>

*insert Table 5.5.5.6 metric units*

Revise Section 5.7 as follows:

### 5.7.5

A list of linear thermal bridges and point thermal bridges as identified in Section 5.5.5 that are declared to be present on the proposed building with one of the following included in each case:

- "COMPLIES WITH SECTION 5.5.5.X, Exception X(x)"
- "COMPLIES WITH SECTION 5.5.5.6"

Revise Section 5.7.5 (of the 2019 standard) as follows:

### 5.7.5 Permit Application Documentation

Application documents shall include, at a minimum, the type and rated R-value of insulation for each product; opaque door schedule showing the U-factor for each opaque door product as
determined in accordance with Section 5.8.2; fenestration schedule showing the manufacturer, model number, orientation, area, $U$-factor, SHGC, and VT for each fenestration product as determined in accordance with Section 5.8.2; and air leakage details in accordance with Section 5.4.3; and thermal bridge details in the proposed building shall be represented on the compliance documents in accordance with Section 5.5.5.

In addition:

a. Labeling of Space-Conditioning Categories: For buildings that contain spaces that will be only semiheated space or unconditioned space, and compliance is sought using the semiheated space building envelope criteria, such spaces shall be clearly indicated on the floor plans.

b. Labeling of Daylight Areas: Daylighting documentation shall identify daylight areas on floor plans, including the primary sidelighted areas, secondary sidelighted areas, daylight area under skylights, and daylight area under roof monitor.

5.8.2 Fenestration and Doors

5.8.2.1...
5.8.2.2...

5.8.2.3. **Manufacturer’s Installation Instructions.** Fenestration products shall be installed in accordance with manufacturers’ instructions.

*Renumber subsequent sections*
Modify Chapter 11, Table 11.5.1 as follows:

Table 11.5.1 Modeling Requirements for Calculating Design Energy Cost and Energy Cost Budget

<table>
<thead>
<tr>
<th>Proposed Design (Column A) Design Energy Cost (DEC)</th>
<th>Budget Building Design (Column B) Energy Cost Budget (ECB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Building Envelope</td>
<td></td>
</tr>
</tbody>
</table>

All components of the building envelope in the proposed design shall be modeled as shown on architectural drawings or as installed for existing building envelopes. All uninsulated assemblies and linear thermal bridges and point thermal bridges as identified in Section 5.5.5.1 thru 5.5.5.5 (e.g., projecting balconies, perimeter edges of intermediate floor slabs, concrete floor beams over parking garages, roof parapet) shall be modeled using either of the following techniques:

a. Separate model of each of these assemblies within the energy simulation model.

b. When present, uninsulated assemblies and linear thermal bridges or point thermal bridges as identified in Section 5.5.5.1 thru 5.5.5.5 shall be modeled by adjusting the U-factor in accordance with Appendix A10.

Exceptions: The following building elements are permitted to differ from architectural drawings.

1. Linear thermal bridges and point thermal bridges as identified in Section 5.5.5 shall be modeled using any of the following techniques:
   a. By a separate model of each of these assemblies within the energy simulation model.
   b. For linear thermal bridges or point thermal bridges as identified in Section 5.5.5.1 thru 5.5.5.5 by adjusting the U-factor in accordance with Appendix A10.

2. Uninsulated assemblies not identified in Section 5.5.5, shall be modeled using either of the following techniques:
   a. By a separate model of each of these assemblies within the energy simulation model.
   b. By a separate calculation for uninsulated assemblies not identified in Section 5.5.5. The U-factors of these assemblies are then averaged with larger adjacent surfaces using an area-weighted average method. This average U-factor is modeled within the energy simulation model.

3. Any other building envelope assembly, not subject to the requirements of Section 5.5.5, that covers less than 5% of the total area of that assembly type (loss of construction (e.g., exterior walls), need not be separately described, provided that it is similar to an assembly being modeled. If not separately described, the U-factors of these assemblies are then averaged with larger adjacent surfaces using an area-weighted average method. This average U-factor is modeled within the energy simulation model. Area of a building envelope assembly must be added to the area of the adjacent assembly of that same type.

   a. Opaque assemblies, such as roof, floors, doors, and walls, shall be modeled as having the same heat capacity as the proposed design but with the minimum U-factor required in Section 5.5 for new buildings or additions and Section 5.1.3 for alterations.
   b. Where linear thermal bridges and point thermal bridges as identified in Sections 5.5.5.1 thru 5.5.5.5 are modeled in the proposed design, they shall be represented as modified modeled by adjusting the U-factors by adjusting of the parent assembly U-factor in accordance with the default values in Appendix A10. If the proposed design does not have Linear thermal bridges and point thermal bridges, as identified in Sections 5.5.5.1 thru 5.5.5.5, they shall not be modeled in the budget building design.

   If the balcony length in the proposed design exceeds the maximum allowed by Section 5.5.5.2, Exception 2(c)(i), the area shall be reduced proportionally for each balcony until the limit set in Section 5.5.5.2, Exception 2(c)(i) is met.

   c. The exterior roof surfaces shall be modeled with a solar reflectance and thermal emittance as required in Section 5.5.3.1.1(a). All other roofs, including roofs exempted from the requirements in Section 5.5.3.1.1, shall be modeled the same as the proposed design.
   d. No shading projections are to be.......

(remainder unchanged)
Add new standards to Chapter 12 Normative References

International Organization for Standardization (ISO)
1, rue de Varembe, Case postale 56, CH-1211 Geneve 20, Switzerland

ISO 10211 (2017)
Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations

ISO 14683 (2017)
Thermal bridges in building construction – Linear thermal transmittance – Simplified methods and default values

Revise Normative Appendix A as follows:

(This is a normative appendix and is part of this standard.)

Normative Appendix A

Rated R-Value of Insulation And Assembly U-Factor, C-Factor, and F-Factor Determinations, and Thermal Bridging Determinations

Revise Appendix A, Section A1 as follows:

A1. General

A1.1 Pre-Calculated Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities...

A1.2 Applicant-Determined Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities...

A1.3 Applicant-Determined Psi-Factors and Chi-Factors for Thermal Bridges. The applicant shall determine appropriate values for point thermal bridges and linear thermal bridges using the assumptions in Section A10.

A2.2.2 Rated R-Value of Insulation
For roofs with insulation entirely above deck, the rated R-value of insulation is for continuous insulation.

Exception to A2.2.2
Interruptions for framing and pads for mechanical equipment are permitted with a combined total area not exceeding one percent of the total opaque assembly area.

Add a new Section A10 as follows:
A10 Thermal Bridging Chi Factors And Psi Factors

A10.1 Determination of Psi-factors and Chi-factors. Psi-factor (ψ) and Chi-factor (χ) values representative of an as-built as-designed thermal bridging condition shall be determined in accordance with one of the following:

1. Values derived from simulation models compliant with ISO 10211 using details representative of the actual construction and modeling assumptions consistent with accepted architectural and engineering practice.
2. From ISO 14683.
3. From testing of the assembly in accordance with ASTM C1363 with and without the presence of the thermal bridge condition to determine a linear transmittance value or point transmittance value for the thermal bridge condition.
4. Values as indicated in Table A10.1. The default column shall be used where the thermal bridge meets prescriptive requirements. The unmitigated column shall be used where the thermal bridge does not meet the prescriptive requirements.

Insert new table A10.1 Imperial

<table>
<thead>
<tr>
<th>Class of Construction - Wall, above Grade</th>
<th>Thermal Bridge Type</th>
<th>Section</th>
<th>Un-mitigated Psi-Factor Btu/(h·ft·°F)</th>
<th>Un-mitigated Chi-Factor Btu/(h·°F)</th>
<th>Default Psi-Factor Btu/(h·ft·°F)</th>
<th>Default Chi-Factor Btu/(h·°F)</th>
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</thead>
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<td>0.140</td>
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<td>0.151</td>
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<td>0.177</td>
<td></td>
</tr>
<tr>
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<td>5.5.5.2.2</td>
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<td></td>
<td>0.177</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>0.177</td>
<td>n/a</td>
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<td>Wood-framed and Other</td>
<td>Unmitigated</td>
<td>Default</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
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<td>0.179</td>
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<table>
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<th>Default</th>
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<tbody>
<tr>
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<td>Cladding Support</td>
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n/a = not applicable

Insert new table A10.1 Metric

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<th>Table A10.1 Thermal Bridging Default Psi-Factors and Chi-factors for Thermal Bridges</th>
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<table>
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<th><strong>Class of Construction - Wall, above Grade</strong></th>
<th><strong>Thermal Bridge Type</strong></th>
<th><strong>Section</strong></th>
<th><strong>Psi-Factor</strong></th>
<th><strong>Chi-Factor</strong></th>
<th><strong>Psi-Factor</strong></th>
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<td>Value 3</td>
<td>Value 4</td>
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<td>5.5.5.4</td>
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<td>0.143</td>
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<td>n/a</td>
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n/a = not applicable
Informative Note

Table A10.1: The default values for thermal bridge details prescribed in Section 5.5.5 are based on data from ASHRAE Research Project 1365 and the BC Hydro Thermal Bridging Guide listed in Informative Appendix E. As a matter of convenience, a linear thermal bridge includes linear elements that may be connected to the building structure by a series of point load connections that are characterized as a linear thermal bridge by way of a Psi-factor (linear thermal transmittance) rather than as individual point thermal bridges, each having a Chi-factor (point thermal transmittance).

A10.2 Assembly U-factor Adjustment for Simulation of Thermal Bridges. For the purpose of incorporating the effects of thermal bridges in simulations as required by Chapter 11 and Appendix G, where a thermal bridge is not modeled as a separate element, the clear-field U-factors of modeled assemblies shall be permitted to be modified in accordance with Equation A10.2. This modification shall be achieved in the simulation model by altering the conductance value assigned to any one or more insulation layers within the modeled assembly without altering the properties of modeled building material layers.

\[
U_{tot} = ( \left( \sum \psi_i \cdot L_i \right) + \left( \sum \chi_i \cdot n_i \right) ) / A_{total} + U_o \quad (A10.2)
\]

where

- \( U_{tot} \) = overall thermal transmittance including the effect of linear thermal bridges and point thermal bridges not included in the construction assembly's \( U_o \)-factor value, Btu/(h·ft²·°F) or W/(m²·K)
- \( U_o \) = clear field thermal transmittance of the construction assembly as determined in accordance with Section 5.5.5.1, Btu/(h·ft²·°F) or (W/(m²·K))
- \( A_{total} \) = total opaque projected surface area of the construction assembly, in ft² (m²)
- \( \psi_i \) = Psi-factor, thermal transmittance for each type of linear thermal bridge, Btu/(h·ft·°F) (W/(m·K))
- \( L_i \) = length of a particular linear thermal bridge as measured on the outside surface of the building envelope, ft (m)
- \( \chi_i \) = Chi-factor, thermal transmittance for each detail type of point thermal bridge, Btu/(h·°F) (W/K)
- \( n_i \) = the number of occurrences a particular type of point thermal bridge

A10.3 Determining the Proposed Design Psi and Chi Factors. The default column shall be used if where the thermal bridge meets prescriptive requirements. The unmitigated column shall be used if where the thermal bridge does not meet the prescriptive requirements.

Revise Normative Appendix C, Section C1 as follows:

C1.2.7 For Thermal Bridges Identified in Section 5.5.5

Thermal bridge inputs and specifications shall be individually identified for the thermal bridges indicated in Sections 5.5.5.1 through 5.5.5.5 according to either a, b, or c below one of the following:

- a. If the thermal bridge complies with one of the requirements of Sections 5.5.5.1 through 5.5.5.5, then no additional inputs shall be required.
- b. If the thermal bridge does not comply with one or more of the requirements of Sections 5.5.5.1 through 5.5.5.5, then the linear thermal bridge type or point thermal bridge type, length or count, the assembly interrupted by this thermal bridge, and the Psi-factor or Chi-Factor shall be specified. The input shall be a user defined value or one of the values from Table A10.1.
c. If the thermal bridge is not applicable to Section 5.5.5, Sections 5.5.5.1 through 5.5.5.5, including exceptions, are not applicable to the thermal bridge, then no additional inputs shall be required.

Revise Normative Appendix C, Section C2 as follows:

C2.9
For thermal bridges,
  a. that the proposed design complies with the each of the requirements of Sections 5.5.5.1 through 5.5.5.5 including exceptions or
  b. if the proposed design does not comply with each of the individual requirements of Sections 5.5.5.1 through 5.5.5.5 then list the thermal bridges, the proposed Psi-factors, proposed Chi-factors, and source information.

Revise Normative Appendix C, Section C3.5.5 as follows:

C3.5 Calculation of Proposed Envelope Performance Factor
...

C3.5.4 Thermal Bridges

Thermal bridges in the Proposed Design shall be either:
  a. Not modeled if option a or c is selected in Section C1.2.7.
  b. Entered as individual thermal bridge inputs of length or count if option b is selected in Section C1.2.7 and addressed as follows.
     1. Individual thermal bridges in the proposed design that are indicated to comply with the requirements of Sections 5.5.5.1 through 5.5.5.5 need not be modeled,
     2. Individual thermal bridges in the proposed design that are indicated to not comply with the requirements of Sections 5.5.5.1 through 5.5.5.4 5 shall be modeled, or
     3. Individual thermal bridges in the proposed design that are indicated to be “not applicable” with the requirements of Sections 5.5.5.1 through 5.5.5.4 5 need not be modeled.

Revise Normative Appendix C, Section C3.6 as follows:

C3.6 Calculation of Base Envelope Performance Factor

The simulation model for calculating the base envelope performance factor shall modify the simulation model for calculating the proposed envelope performance factor as follows:
  a. All opaque assemblies shall be modeled with the maximum U-factor not greater than that required in Section 5.5.3 for the appropriate class of construction, space-conditioning category, and climate zone. Mass walls and mass floors shall be modeled with HC equal to 7.2 Btu/ft²·°F (1.04 W/(m·K)). All other opaque assemblies shall be modeled with the same HC as the proposed design. Mass walls shall be modeled with equal mass on each side of the insulation. All other opaque assemblies shall be modeled with insulation on the exterior. Thermal bridges shall modify assembly U-factors in accordance with item C3.6b.
  b. Thermal Bridges:
b1. Where option a is selected in Section C1.2.7 then no modifications to the assembly U-factors are required.

b2. Where option b is selected in Section C1.2.7 then the U-factor of the assembly interrupted shall be modified per section A10.2 utilizing the default values in Table A10.1 for the appropriate class of construction. Each of the linear thermal bridges or point thermal bridges identified in Sections 5.5.5.1 through 5.5.5.5 shall be modeled in the simulation model for calculating the proposed envelope performance. Where the balcony length in the proposed design exceeds the maximum allowed by Section 5.5.5.2.2, Exception 2c.i, the area shall be reduced proportionally along each exposure until the limit set in Section 5.5.5.2.2, Exception 2c.i is met.

b3. Where option c is selected in Section C1.2.7 then no modifications to the assembly U-factors are required.

(re number following sub-sections.....)

Revise Informative Appendix E as follows:

Informative References
This appendix contains informative references for the convenience of users of Standard 90.1 and to acknowledge source documents when appropriate. Some documents are also included in Section 12, “Normative References,” because there are other citations of those documents within the standard that are normative.

(Add the following informative documents)

ASHRAE
1791 Tullie Circle
Atlanta, GA 30329-2305

www.ashrae.org

BC Hydro
Corporate Head Office
333 Dunsmuir Street
Vancouver, B. C. V6B 5R3

https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal

Modify Appendix G, Table G3.1 as follows:

<table>
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<th>No.</th>
<th>Proposed Building Performance</th>
<th>Baseline Building Performance</th>
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<tr>
<td>5. Building Envelope</td>
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</tbody>
</table>
Add informative Appendix J as follows:

All components of the building envelope in the proposed design shall be modeled as shown on architectural drawings or as built for existing building envelopes.

Exceptions: The following building elements shall be permitted to differ from architectural drawings:

b. 1. All uninsulated assemblies and linear thermal bridges and point thermal bridges as defined in Section 5.5.5 (e.g., projecting balconies, perimeter edges of intermediate floor slabs, concrete floor beams over parking garages, roof parapets) shall be modeled using either any of the following techniques:
   a. By a separate model of each of these assemblies within the energy simulation model.
   b. For linear thermal bridges or point thermal bridges as identified in Section 5.5.5.1 thru 5.5.5.5 shall be modeled by adjusting the U-factor of the assembly interrupted in accordance with Appendix A10.

2. Uninsulated assemblies not identified in Section 5.5.5, shall be modeled using either of the following techniques:

   a. A separate model of each of these assemblies within the energy simulation model.
   b. A separate calculation shall be performed for uninsulated assemblies not identified in Section 5.5.5. The U-factors of these assemblies are then averaged with larger adjacent surfaces using an area-weighted average method. This average U-factor is modeled within the energy simulation model.

Exceptions: The following building elements shall be permitted to differ from architectural drawings:

2-3. Any other building envelope assembly, that covers less than 5% of the total area of that assembly type/class of construction (e.g., exterior walls) need not be separately described, provided that it is similar to an assembly being modeled. If not separately described, the U-factors of these assemblies are then averaged with larger adjacent surfaces using an area-weighted average method. This average U-factor is modeled using the energy simulation model area of a building envelope assembly shall be added to the area of an assembly of that same type with the same orientation and thermal properties.

3. Exterior surfaces whose azimuth orientation and tilt differ by less than 45 degrees and are otherwise the same may be described as either a single surface or by using multipliers.

(REMAINDER UNCHANGED)
Informative Figures

This appendix contains informative reference figures for Sections 5.5.5.1 through 5.5.5.4 for the convenience of the user of Standard 90.1 and not for use as specific details required for compliance. These figures are not intended to include all detailed variations that may meet the requirements. It is not intended that the figures represent all possible compliant configurations. The figures do not show roof membrane or wall cladding.

Symbols

Key:

- Structure
- Continuous Insulation
- Cavity Insulation
- Integral Insulation
- Masonry Unit

--- Point Load Connection (Bolt, Bar, Shear Plate, etc.)

Shading Device, Awning, or Vertical Fin
Section 5.5.5.1 Figures
Note: Blocking permitted by Section 5.5.5.1 Exception 1 not shown.
Section 5.5.5.2 Figures

Figure 5.5.5.2a

Figure 5.5.5.2b

Figure 5.5.5.2c

Figure 5.5.5.2 Exception 1a
Any Wall with Cavity Insulation

Figure 5.5.5.2 Exception 1b
Any Mass Wall with Integral Insulation

Figure 5.5.5.2 Exception 1c(i)
Mass Wall with Interior Insulation
Section 5.5.5.3 Figures

Figure 5.5.5.3a Fenestration and Continuous Insulation

Figure 5.5.5.3b Fenestration and no Continuous Insulation

Figure 5.5.5.3 Exception 1a Insulation between Fenestration and Wall

Figure 5.5.5.3 Exception 1b Insulation between Fenestration and Wall

Section 5.5.5.4 Figures

Figure 5.5.5.4 Shading Devices, Vertical Fins or Awnings

SI Figures
Second Public Review Draft – Independent Substantive Changes