Envelope Performance and Thermal Bridge Derating

Introduction and Applicability

In this code, minimum thermal resistance and air leakage performance is specified for Prescriptive, Targeted, and Relative compliance paths in C401.2.1. The table below lists the sections of the code related to envelope performance required by these three paths. Notably, the code includes new provisions to account for thermal bridges and significantly modified provisions for minimum envelope performance.

Note that envelope performance and derating requirements for Certified Performance (Passive House and HERS) in C401.2.2 are contained entirely within those programs and are not covered in this code.

Envelope Performance Topics and Relevant Sections

C401.3 Thermal envelope certificate	Documents envelope construction.
C402.1.3 Insulation component R-value-based method	This option has been removed in this code.
C402.1.4 Assembly U-factor, C-factor, or F-factor-based method	Prescribes assembly thermal performance for walls, roofs, and floors.
C402.1.5 Component performance alternative	Permits performance tradeoffs within vertical assemblies.
C402.2 Specific building thermal envelope insulation requirements	Describes how insulation is to be installed.
C402.4 Fenestration	Limits thermal transmittance and solar heat gain for windows.
C402.5 Air leakage – thermal envelope	Limits whole-building or dwelling unit air leakage rate with specific requirements for individual components.
C402.7 Derating and thermal bridges	Modifies wall performance to account for thermal bridges.
ASHRAE 90.1 2018 Appendix A	Contains pre-solved thermal performance values which account for wall framing thermal bridges.

Informative Note

The Stretch and Specialized codes are designed to minimize the need for heating and, for buildings with electrified space heating, to minimize winter peak electric use. To achieve these goals, Massachusetts has amended the IECC envelope performance section in two ways:

- Massachusetts amendments limit how much envelope performance can be traded off with other energy efficiency improvements in the building by establishing minimum mandatory envelope performance limits. Massachusetts has had minimum mandatory limits on envelope performance for several years. Those limits have been further modified and now also include an accommodation for buildings with more than 50% of the vertical envelope being *glazed wall systems*.

- Massachusetts amendments now include accounting for thermal bridges and credit for thermal bridge mitigation. Excepting the thermal bridging caused by wall framing studs, the existing IECC code does not have provisions related to thermal bridges and does not give credit to thermal bridge mitigation.

R-value and U-factor

Section C402.1.3 of IECC describes the “R-value method”. This method describes the mandatory rated insulation R-value that must be installed either in the cavity between wall framing studs or in a continuous fashion outboard of the wall framing studs. This R-value method has been removed from the Stretch and Specialized code and is no longer a compliance option in these codes. The reason this section has been removed is that the R-value method is insufficient to prescribe performance in combination with thermal bridging requirements.

Only Sections C402.1.4 or C402.1.5, the U-factor methods, are available for compliance. These U-factor methods specify the performance of the whole assembly and are compatible with thermal bridge derating requirements.

Minimum Allowable Envelope Performance

When showing compliance with minimum allowable envelope performance, there are two choices:

- “Prescriptive compliance” (C402.1.4). With this approach, each opaque and vision element needs to individually meet or exceed specified performance factors AND the vision areas cannot exceed set limits in C402.4.

- “Flexible compliance” (C402.1.5). With this approach, with one exception, the performance factors AND vision areas of the above-grade *vertical* elements are flexible, so long as overall above-grade vertical performance meets certain standards. The exception is: any vision sections within a *glazed wall system* must meet certain performance factors. *Horizontal* and below-grade elements still need to individually meet or exceed specified performance factors AND horizontal vision elements (e.g. skylights) must be within specified areas.

Prescriptive Compliance (C402.1.4 and C402.4)

Each horizontal and vertical envelope assembly must meet the applicable U-factor (or C- and F-factors for assemblies in contact with the ground) in Table C402.1.4. **Notably, all above grade wall U-factors must include derating calculations in C402.7 and still achieve the values in Table C402.1.4**.

Where this compliance path (C402.1.4) is used, the fenestration area is limited to 30% as specified in C402.4.1 unless the building includes the daylighting areas and controls described in C402.4.1.1 (See additional information below). If all the C402.4.1.1 conditions are met, the fenestration area can be increased to 40%. Window performance requirements are in C402.4.

Additional Information

What do I have to do to qualify for C402.4.1.1?
Section C402.4.1.1 allows 40%, rather than 30%, vertical vision area if the extensive requirements and detailed calculations for daylighting and daylight controls of C405.2.4 are met. The design must be sufficiently detailed to show full compliance with C405.2.4 at the time of building permit. Core and shell buildings would not be able to provide these details at the time of building permit and thus would not be able to quality for 40% window to wall ratio limit

Flexible Compliance (C402.1.5 and C402.4)

Section C402.1.5 retains and extends modifications from the last code cycle to allow flexibility among the above-grade vertical envelope assemblies. This option allows deviation from the above-grade *vertical* envelope requirements in Table C402.1.4 and deviation from the vision limits in C402.4, provided that the overall above-grade vertical envelope performance achieves specified area-weighted performance and other conditions are met.

Note that *horizontal* envelope performance can no longer be traded off against vertical envelope performance in this pathway. Only above-grade vertical walls and vertical vision elements are available for tradeoff. Each horizontal above-grade element (roof, floors, and slab-on-grade floors) and vertical below-grade walls must meet the applicable U-factor in Table C402.1.4.

As with prescriptive compliance, **all above-grade wall U-factors must include derating calculations in C402.7 and still achieve the specified area-weighted performance.**

The required vertical envelope area-weighted U-factor is based on the amount of *glazed wall system* making up the vertical area.

- Where less, or exactly half, of the above-grade vertical envelop is *glazed wall system*, this is considered a low *glazed wall system* building and C402.1.5.1 would be used and an area weighted U-factor of 0.1285 Btu/hr-ft2-F, or less, must be achieved for the vertical above-grade performance.

- Where more than half of the vertical envelope area is *glazed wall system*, this is considered a high *glazed wall system* building and C402.1.5.2 would be used and an area weighted U-factor of 0.1600 Btu/hr-ft2-F, or less, must be achieved for the vertical above-grade performance.

The vision section within a *glazed wall system* must have whole assembly U-factor (not “center of glass” U-factor) performance of U-0.25 or less. “Whole assembly U-factor” means that the U-0.25 performance takes into account the effect of mullions and connections within and adjacent to the vision section.

Vertical vision areas which are not within a *glazed wall system* do not have to have performance of U-0.25 or less.

High *glazed wall system* buildings have electrification requirements. Specifically, high *glazed wall system* buildings are required to have full space heating electrification, per C401.4.2 unless the building is using the Relative Performance pathway because average ventilation at full occupancy is greater than

0.5 cfm/sf, in which case the building would be required to have partial space heating electrification per C401.4.1.

Additional Information

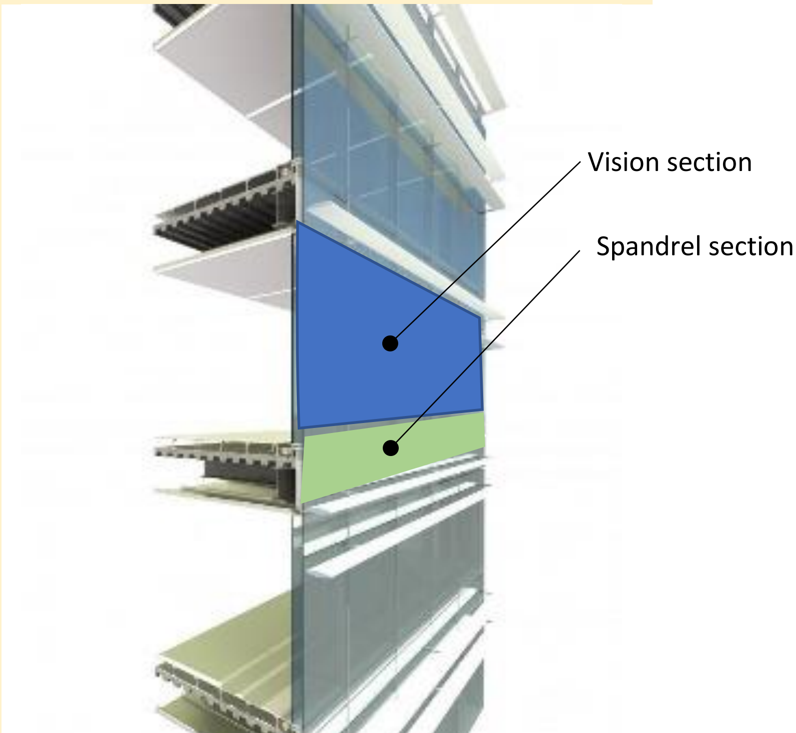
What is a *glazed wall system?* Within a *glazed wall system*, what is the *spandrel section* and what is the vision section?

A ***GLAZED WALL SYSTEM*** consists of any combination of both vision glass and/or *spandrel sections* to create an above-grade wall that is designed to separate the exterior and interior environments. These systems include, but are not limited to, curtain walls, window walls, and storefront windows.

The ***SPANDREL SECTION*** is the opaque portion of a *glazed wall system* typically used to conceal or obscure features of the building structure or used for visual effect. A *spandrel section* may consist of, but is not limited to, an exterior exposed cladding layer (glazing or opaque material) with an interior insulated panel.

The **VISION SECTION** is the transparent area between the spandrels within the *glazed wall system*.

In summary, *Glazed wall systems* are comprised two sections: (a) the *spandrel section* and (b) the vision section. The spandrel section is opaque, and the vision section is transparent. The area of the *glazed wall system* is equal to the area of the *spandrel section* plus the area of the vision section.

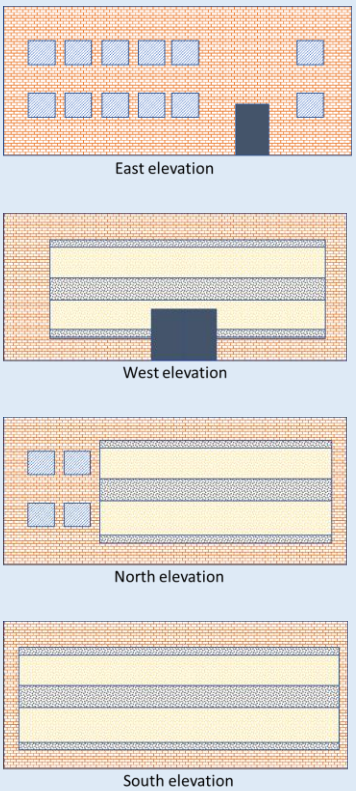


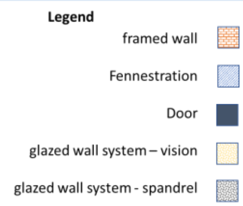
Orthogonal view of a *glazed wall system* showing the spandrel section (green) and the vision section (blue) for one of the floors.

Calculation

How to determine if building is high glazed or low glazed.

The example below shows the steps in determining whether a building is a high *glazed wall system* building or a low *glazed wall system* building.





East elevation	
	area (sf)
framed wall	1,874
fennestration	108
door	18
glazed wall system - vision	-
glazed wall system - spandrel	-

West elevation	
	area (sf)
framed wall	364
fennestration	-
door	36
glazed wall system - vision	1,280
glazed wall system - spandrel	320

North elevation	
	area (sf)
framed wall	764
fennestration	36
door	-
glazed wall system - vision	960
glazed wall system - spandrel	240

North elevation	
	area (sf)
framed wall	560
fennestration	-
door	-
glazed wall system - vision	1,080
glazed wall system - spandrel	360

Total building		
	area (sf)	% of total vertial
framed wall	3,562	45%
fennestration	144	2%
door	54	1%
glazed wall system - vision	3,320	42%
glazed wall system - spandrel	920	12%
total vertial area	8,000	
% of vertical that is glazed wall system		53%

The areas of each unique assembly for each vertical face are summed to obtain building totals. The vision and spandrel sections (red text) of the *glazed wall system* are summed to obtain a total percent of *glazed wall system*. If this percent is larger than 50%, the building is a high *glazed wall system* building. If this percent is 50% or less, the building is a low *glazed wall system* building.

Calculating Area-weighted U value when using C402.1.5

As noted above, the flexible compliance path (C402.1.5) requires the area-weighted U value for all vertical faces be U-0.1285 Btu/hr-ft2-F, or less, for a low *glazed wall system* building or U-0.1600 Btu/hr-ft2-F, or less, for a high *glazed wall* system building. The following example shows how to calculate this area-weighted value.

Calculation

How to calculate area-weighted vertical U

The example calculation below continues from the previous calculation example. The table below presents areas for each unique assembly, totaled for the building, and the respective U-value for each assembly.

Calculate the building's area-weighted U value by multiplying each percent area by the respective U value, then summing. U values should be shown to 4 decimals.

Total building				
	area (sf)	**% of total vertial**	**U value (after derating)**	**U-value times percent of total vertical**
framed wall	3,562	45%	0.0435	0.0194
fennestration	144	2%	0.2381	0.0043
door	54	1%	0.3333	0.0022
glazed wall system - vision	3,320	42%	0.2300	0.0955
glazed wall system - spandrel	920	12%	0.1667	0.0192
total vertial area	8,000		Area-weighted U of building	0.1405
			Area-weighted U required	0.1600

This building is a high *glazed wall system* building. The maximum allowed area-weighted U-value is U-0.1600. This building has an area-weighted U value of U-0.1405. Accordingly, this building would meet the area-weighted requirement. Note that the vision section of the glazed wall system has U-0.23 which exceeds mandatory requirements for the vision section.

Note also that walls and spandrels need to be derated for thermal bridges per C402.7.

Derating for Thermal Bridges

What is a Thermal Bridge?

A thermal bridge is an interruption in an envelope assembly which reduces the overall thermal performance of the assembly. These interruptions allow unwanted heat transmission because they bypass the surrounding assembly insulation.

The interruption causing a thermal bridge could be the result of a penetration in the assembly. Examples of this include supports for exterior wall cladding or rainscreen, supports for brick cladding, brick shelves, balcony supports, and wall framing.

The interruption could also be caused by architectural transitions. Examples of this include building corners, vertical wall to roof transition (e.g. parapet), wall to window intersections, and intersection of interior floor to exterior vertical wall.

Together these *thermal bridges* reduce the effectiveness of surrounding insulation. Unless these thermal bridges are mitigated, the impact to surrounding insulation can be significant.

Thermal Bridge Classification and Number

There are three classifications of thermal bridges described in the code, as outlined below. Further, the code now identifies eleven specific types of thermal bridges. (The numbers shown below are used throughout this Guideline.) Thermal bridges are as follows:

CLEAR FIELD: A thermal bridge that is uniformly distributed throughout an assembly such that accounting for the thermal bridge individually is impractical for whole-building calculations. The following *clear field* thermal bridges require derating in the code:

1. Cavity insulation between wall framing
2. Fasteners which hold exterior cladding (wall paneling/rainscreen) to the framing
3. Brick ties which hold brick panel sections to the framing

LINEAR: A thermal bridge that is continuous in one direction of the exterior envelope. The following linear thermal bridges require derating in the code:

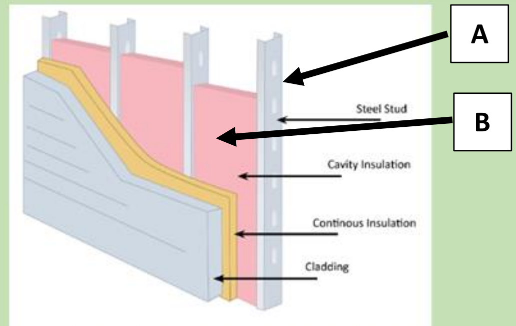
4. Balcony to exterior vertical wall intersection
5. Interior horizontal floor to exterior vertical wall intersection
6. Interior vertical wall to exterior vertical wall intersection
7. Fenestration to exterior vertical wall intersection
8. Exterior vertical wall to roof intersection (e.g. parapet)
9. Brick shelfs
10. Exterior vertical wall to grade intersection
11. Exterior vertical wall plane transition, such as building corners and other changes in the plane of the vertical wall face

A third classification of thermal bridge also exists and is defined in the code: POINT thermal bridge. These are thermal bridges at discrete locations such as plumbing penetrations. At this time, the code does not explicitly mandate derating due to these penetrations.

Finally, *glazed wall systems* typically contain framing and structural components which create thermal bridges. The code now requires that thermal bridges within *glazed wall systems* be taken into account.

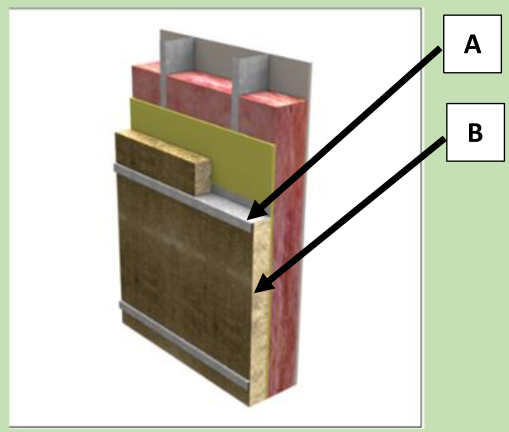
Thermal bridge 1: Cavity insulation between wall framing

Wall framing (A), which can be wood or metal, interrupt the "cavity" insulation on the inboard side of the assembly (B).



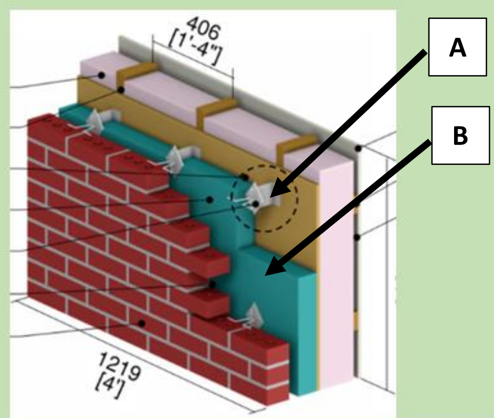
Thermal bridge 2: Fasteners which hold exterior wall cladding (paneling/rainscreen) to the framing studs

Fasteners (A) which are used to connect the exterior paneling/rainscreen (not shown) and/or support exterior insulation interrupt the exterior insulation (B)



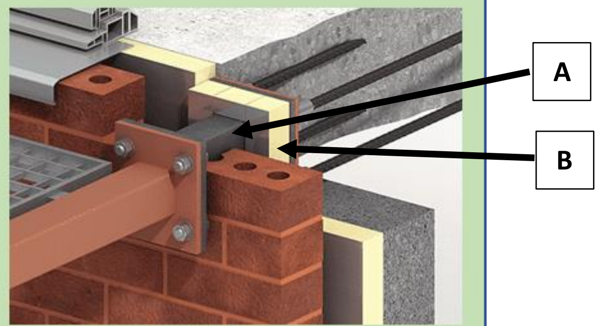
Thermal bridge 3: Brick ties which hold brick panel sections to framing studs

Brick ties (A) which are used to connect the exterior brick to the building framing interrupt the exterior insulation (B)



Thermal bridge 4: Balcony to exterior wall intersection

Structural connections (A) which are used to connect the balcony to the building framing bypass all insulation.



Repeat for 5 through 11

What's New

Thermal bridge Number 1 (Framing studs) is the only thermal bridge which requires mandatory derating in the existing IECC and ASHRAE codes. This derating is built into ASHRAE Standard 90.1, Appendix A which is used by both ASHRA and IECC code.

What's new is Section C402.7 of the Massachusetts code now adds mandatory derating for thermal bridges Number 2 through 11, and *glazed wall systems*, for all projects using any of the three compliance pathways in C401.2.1. Derating must be applied prior to showing compliance with the U-value tables (when using C402.1.4) or showing compliance with the weighted average vertical U-value (when using C402.1.5).

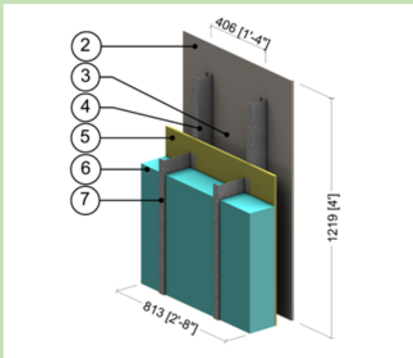
Projects using either of the two compliance pathways in C401.2.2 (HERs and Passivehouse) do not have to perform the derating contained in Section C402.7. The PHIUS and HERs methods have their own thermal bridge accounting systems.

Thermal Bridge Mitigation

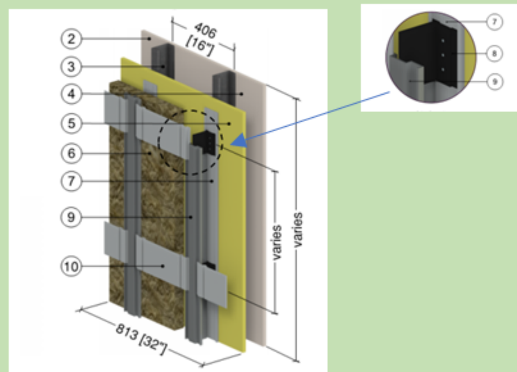
Thermal bridges can be *mitigated* in a variety of ways. For example, wall connections and brick ties can be thermal broken using insulating gaskets or non-metallic connections. Insulating materials can be used to thermally break connections supporting balconies. Framing, connection, and insulation strategies can be used at parapets, wall corners, wall/window intersections, and wall floor intersections which mitigate discontinuities in insulation. Thermal bridge mitigation is highly recommended.

A Tale of Two Details

Thermal breaks make a significant difference. The BC hydro Catalogue contains examples of details which do and do not include thermal breaks. For example, Detail 5.1.5 (left) has wall connections which do not have thermal breaks. In contrast, Detail 5.1.23 (right) has thermal breaks.



<u>Does not have thermal break (Detail 5.1.5)</u> Exterior Insulated Steel-Framed Wall with Vertical Z-Girts Supporting Cladding, BC Hydro



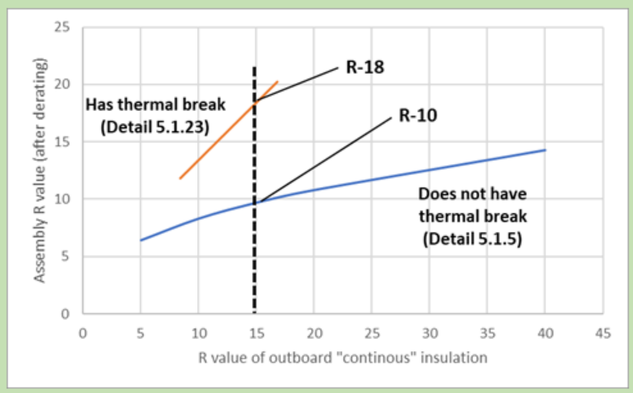
<u>Does have thermal break (Detail 5.1.23)</u>, Exterior Insulated Steel-Framed Wall with Clip System Supporting Cladding, BC Hydro

The illustration to the right shows the derated, overall assembly performance (y-axis) as a function of the R value of outboard continuous insulation (x-axis).

With the same outboard continuous insulation (R-15), the thermally broken assembly (Detail 5.1.23) has almost twice the overall, derated assembly R-value than the derated assembly with no thermal break (Detail 5.1.5) . (R-18 versus R-10.)

Thermal breaks preserve the value of continuous insulation. Without thermal breaks, adding more and more continuous insulation is counterproductive.

For example, even with R-40 outboard continuous insulation, Detail 5.1.5 still does not have the same overall performance as a Detail 5.1.23 with R-15 continuous insulation.



Thermal Bridge Derating: Three Approaches

There are 3 options for derating in the code: prescriptive, reference, and modeled.

- Prescriptive derating – For prescriptive derating, use the derating formulae contained in Section C402.7.2.1 for common clear wall thermal bridges and Section C402.7.3.1 for common liner thermal bridges. Section C402.7.4.1 contains prescriptive derating for the *spandrel section* of *glazed wall systems*. The formulae are based on non-thermally mitigated details and thus the prescriptive approach results in significant derating.

- Reference derating – For reference derating, use the pre-solved derated values contained in Building Envelope Thermal Bridging Guide, version 1.6 or higher, published by BC Hydro Power Smart. This guide contains assemblies with and without thermal mitigation for common clear wall thermal bridges, linear thermal bridges, and *glazed wall systems*. The project's proposed assemblies must match the materials, configuration, and dimensions shown in the guide. An online, easily searchable, version of this guide is available here: https://thermalenvelope.ca/catalogue/

- Modeled derating - For modeled derating, use a finite element analysis heat transfer model. The heat transfer model must have three dimensions for assemblies with thermal bridging in multiple planes.

Any combination of these three can be used for different parts of the building. For example, a building project could use prescriptive derating for Thermal Bridge 4 (Balcony to exterior vertical wall intersection) and Thermal Bridge 9 (Brick Shelves), modeled derating for the *spandrel* section of *a glazed wall system*, and reference derating for the other 9 thermal bridges.

Prescriptive Derating - Clear Field

The process for prescriptive derating of various clear field scenarios is presented below. Prescriptive derating requires using both ASHRAE 2019 Appendix A and Section C402.7.2.1 to obtain a whole assembly result.

Prescriptive derating of steel frame wall, continuous insulation, and building cladding (Thermal Bridges 1 & 2)

To prescriptively derate an assembly consisting of a steel frame wall (which has cavity insulation between the framing), continuous insulation (which is interrupted by fasteners), and building cladding/rainscreen, use ASHRAE 2019 Appendix A Table A3.3.3.1 and Equation C402.7.2.1.

- Table A3.3.3.1 derates for Thermal Bridge 1 (cavity insulation between framing). Use the column "Overall U-factor for entire base assembly" to account for effect of cavity insulation derating to obtain U_{base} and take the inverse to obtain R_{base}. Do not use the U factors shown in any of the columns under "overall U-factor for Assembly of Base Wall Plus Continuous Insulation" as these values do not derate for wall paneling fasteners. The continuous insulation is accounted for in the next step.

- Equation C402.7.2.1 derates for Thermal Bridge 2 (Fasteners which hold exterior wall paneling/rainscreen to the framing). Unless qualifying thermal breaks are used (per Section C402.7.2.1.3), use Table 402.7.2.1.2 to obtain derating factor as a function of continuous insulation thickness (R_o).

Sum R_{base} and R_o to obtain derated whole assembly R-value and whole assembly U-value.

Example:

An assembly consists of a steel frame wall and continuous insulation between the steel frame and the exterior cladding. The steel frame wall has 24-in center to center spacing between frames and has R-11 cavity insulation. The exterior cladding is attached with fasteners with no thermal break. There is R-20 continuous insulation. What is the whole assembly U and R values?

Solution:

From Table A3.3.3.1, U_{base} = 0.116. Using the inverse, R_{base} = 8.62. From Table 402.7.2.1.2 and using R_o=20, the derating factor is 0.41. Using equation C402.7.2.1, $R_{derated}$ = 8.20. The whole assembly, therefore, would have R= 16.82 and U=0.0595.

Section C402.7.2.1.3 allows a more favorable derating factor if thermally-broken fasteners are used. To qualify, the fasteners must be made entirely of material having a thermal conductivity of 3 Btu-in/hr-ft2-F or less. Alternatively, the fasteners must have a thermal break material (having thermal conductivity of 3 Btu-in/hr-ft2-F) or less on both sides of the fasteners. Fasteners with a thermal break on only one side do not qualify for Section C402.7.2.1.3.

Example:

As above, but using a fastener with thermal breaks on both sides of the fastener. Thermal breaks have a conductivity of 2 Btu-in/hr-ft2-F. What is the whole assembly U and R values?

Solution:

From Table A3.3.3.1, U_{base} = 0.116. Using the inverse, R_{base} = 8.62. Qualifying fasteners have derating factor of 0.8 per Section C402.7.2.1.3. Using equation C402.7.2.1, $R_{derated}$ = 8.20. The whole assembly, therefore, would have R= 24.62 and U=0.0406.

Prescriptive derating of wood frame wall, continuous insulation, and building cladding (Thermal Bridges 1 & 2)

To prescriptively derate an assembly consisting of a wood frame wall (which has cavity insulation between the framing) continuous insulation (which is interrupted by fasteners), and building cladding, use ASHRAE 2019 Appendix A Table A3.4.3.1, Equation C402.7.2.1, and the process as above.

Prescriptive derating of concrete wall, continuous insulation, and building cladding (Thermal Bridge 2)

To prescriptively derate an assembly consisting of a concrete wall, continuous insulation (which is interrupted by fasteners), and building cladding, use ASHRAE 2019 Appendix A Table A3.1-2 and Equation C402.7.2.1.

- Table A3.1-2 provides the U-factor of the concrete wall as a function of density and wall thickness. In this case, there is no Thermal Bridge 1. Take the inverse of the U-factor for R_{base}

- As above, Equation C402.7.2.1 derates for Thermal Bridge 2 (Fasteners which hold exterior wall paneling/rainscreen to the framing). Unless qualifying thermal breaks are used (per Section C402.7.2.1.3), use Table 402.7.2.1.2 to obtain derating factor as a function of continuous insulation thickness (R_o).

Sum R_{base} and R_o to obtain derated whole assembly R value and whole assembly U value.

> Example:
>
> An assembly consists of a 9-in thick, 125-lbs/ft3 concrete wall and continuous insulation between the wall and the exterior cladding. The exterior cladding is attached with fasteners with no thermal break. There is R-20 continuous insulation. What is the whole assembly U and R values?
>
> Solution:
>
> From Table A3.1-2, U_{base} = 0.600. Using the inverse, R_{base} = 1.67. From Table 402.7.2.1.2 and using R_o=20, the derating factor is 0.41. Using equation C402.7.2.1, $R_{derated}$ = 8.20. The whole assembly, therefore, would have R= 9.87 and U=0.1013.

If fasteners with qualifying thermal breaks are used, a derating factor of 0.8 could be used in the above example.

Prescriptive derating of masonry wall, continuous insulation, and building cladding (Thermal Bridge 2)

To prescriptively derate an assembly consisting of a masonry wall, continuous insulation (which is interrupted by fasteners), and building cladding, use ASHRAE 2019 Appendix A Table A3.1-3 and Equation C402.7.2.1.

- Table A3.1-3 provides the U-factor of the masonry wall as a function of masonry block size, density, and grouting and cell treatment. In this case, there is no Thermal Bridge 1. Take the inverse of the U-factor for R_{base}

- As above, Equation C402.7.2.1 derates for Thermal Bridge 2 (Fasteners which hold exterior wall paneling/rainscreen to the framing). Unless qualifying thermal breaks are used (per Section C402.7.2.1.3), use Table 402.7.2.1.2 to obtain derating factor as a function of continuous insulation thickness (R_o).

Sum R_{base} and R_o to obtain derated whole assembly R value and whole assembly U value.

Prescriptive derating with brick panel sections (Thermal Bridges 1 & 3)

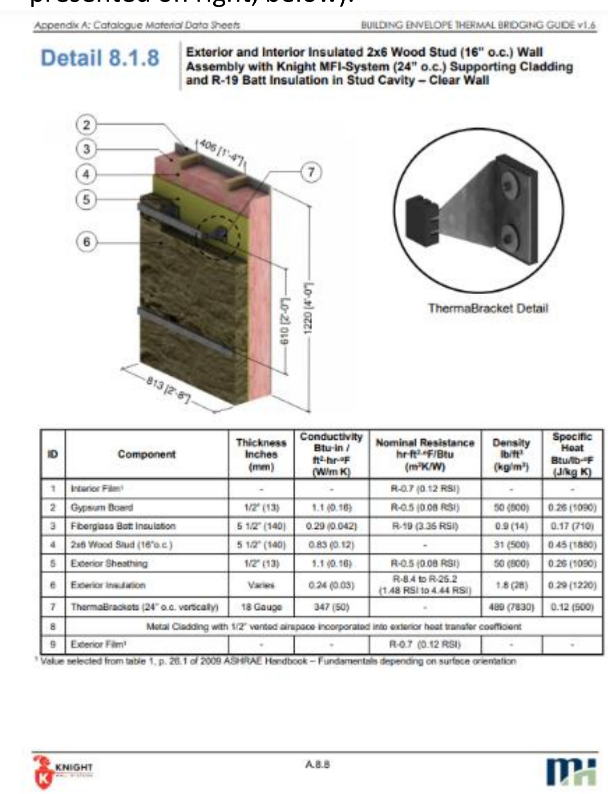
To prescriptively derate an assembly consisting of either a steel frame, wood frame, concrete, or masonry wall, continuous insulation (which is interrupted by brick ties), and brick panel sections, use the same processes as above to obtain R_{base} using the appropriate tables for steel frame, wood frame, concrete wall, or masonry wall. As described in Section C402.7.2.1.1, use a Derating Factor of 0.7 in Equation C402.7.2.1 to obtain R_o. Sum R_{base} and R_o to obtain derated whole assembly R value and whole assembly U value.

Note that further derating is required for brick shelve angles (Thermal Bridge 9).

Reference Derating - Clear Field

The process for reference derating of various clear field scenarios is presented below. As described in Section C402.7.2.2, reference derating uses pre-solved solutions available in the Building Envelope Thermal Bridging Guide, version 1.6 or higher, published by BC Hydro Power Smart (the "Guide"). Reference derating does not require ASHRAE 2019 Appendix A because wall framing interruptions are already included in the pre-solved solutions. A searchable database version of the Guide is available here https://thermalenvelope.ca/catalogue/.

Pre-solved assemblies are uniquely numbered in the Guide. Accompanying each assembly is the "Catalogue Material Data Sheets", taken from Appendix A of the Guide (one example is presented on left, below) and "Catalogue Thermal Data Sheets", taken from Appendix B of the Guide (one example is presented on right, below).



Appendix A: Catalogue Material Data Sheets — BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

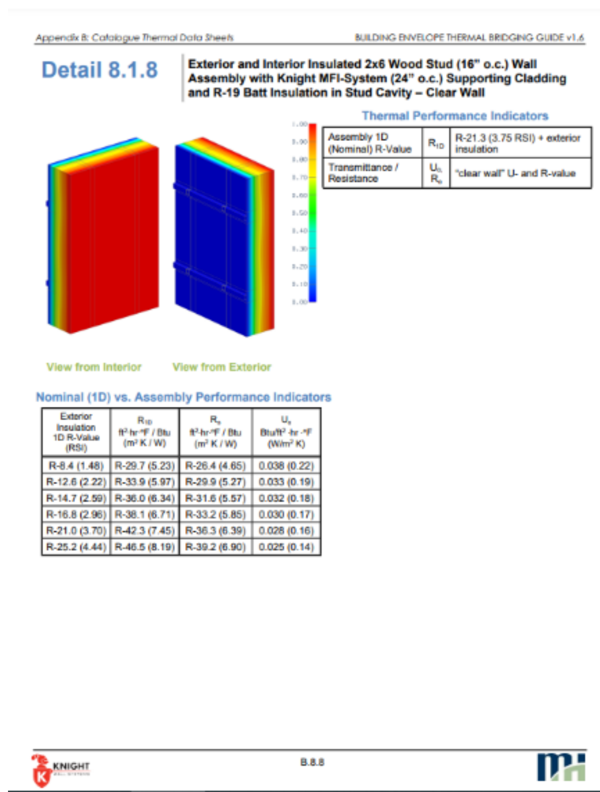
Detail 8.1.8 — Exterior and Interior Insulated 2x6 Wood Stud (16" o.c.) Wall Assembly with Knight MFI-System (24" o.c.) Supporting Cladding and R-19 Batt Insulation in Stud Cavity – Clear Wall

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[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation	5 1/2" (140)	0.29 (0.042)	R-19 (3.35 RSI)	0.9 (14)	0.17 (710)
4	2x6 Wood Stud (16"o.c.)	5 1/2" (140)	0.83 (0.12)	-	31 (500)	0.45 (1880)
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	0.24 (0.03)	R-8.4 to R-25.2 (1.48 RSI to 4.44 RSI)	1.8 (28)	0.29 (1220)
7	ThermaBrackets (24" o.c. vertically)	18 Gauge	347 (50)	-	489 (7830)	0.12 (500)
8	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient					
9	Exterior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-

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

KNIGHT A.8.8

Material Data Sheet for Detail 8.1.8



Appendix B: Catalogue Thermal Data Sheets — BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 8.1.8 — Exterior and Interior Insulated 2x6 Wood Stud (16" o.c.) Wall Assembly with Knight MFI-System (24" o.c.) Supporting Cladding and R-19 Batt Insulation in Stud Cavity – Clear Wall

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-21.3 (3.75 RSI) + exterior insulation
Transmittance / Resistance	U_o, R_o	"clear wall" U- and R-value

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-8.4 (1.48)	R-29.7 (5.23)	R-26.4 (4.65)	0.038 (0.22)
R-12.6 (2.22)	R-33.9 (5.97)	R-29.9 (5.27)	0.033 (0.19)
R-14.7 (2.59)	R-36.0 (6.34)	R-31.6 (5.57)	0.032 (0.18)
R-16.8 (2.96)	R-38.1 (6.71)	R-33.2 (5.85)	0.030 (0.17)
R-21.0 (3.70)	R-42.3 (7.45)	R-36.3 (6.39)	0.028 (0.16)
R-25.2 (4.44)	R-46.5 (8.19)	R-39.2 (6.90)	0.025 (0.14)

KNIGHT B.8.8

Thermal Data Sheet for Detail 8.1.8

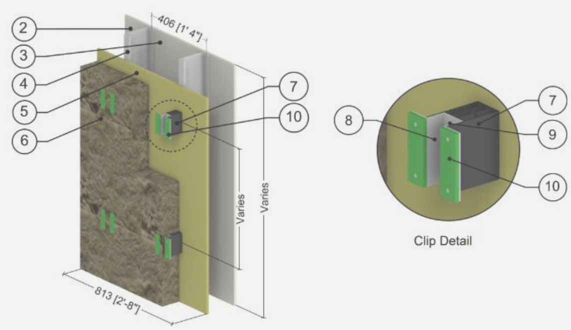
To qualify for reference derating, the proposed assembly must match the materials, dimensions, and other details contained in the Material Data and Thermal Data Sheets for the representative assembly.

Reference derating of steel frame wall, wood framed, concrete, and masonry walls with continuous insulation, and building cladding (Thermal Bridges 1 & 2) or brick panel sections (Thermal Bridges 1 and 3).

The Guide contains pre-solved solutions for all wall types (steel frame, wood frame, concrete, and masonry) with numerous continuous insulation, fastener, wall cladding and brick panel approaches. Approaches have an array of thermal bridging strategies. Whole assembly R and U values, derated for both Thermal Bridge 1 and 2 (or Thermal Bridge 1 and 3) can be taken directly from the Guide with no calculations.

Example

A building project builds an assembly having significant thermal mitigation matching Detail 5.1.94 (Material Data Sheet shown on right) having 36-in vertical clip spacing, and R-16.8 exterior continuous insulation. What is the whole assembly R and U?



Solution

The table from the Thermal Data Sheet for Detail 5.1.94 is reproduced on the right. The whole assembly R value is under the R_o column (R_o=17.6) and whole assembly U value is under the U_o column (U_o=0.057).

Nominal (1D) vs. Assembly Performance Indicators

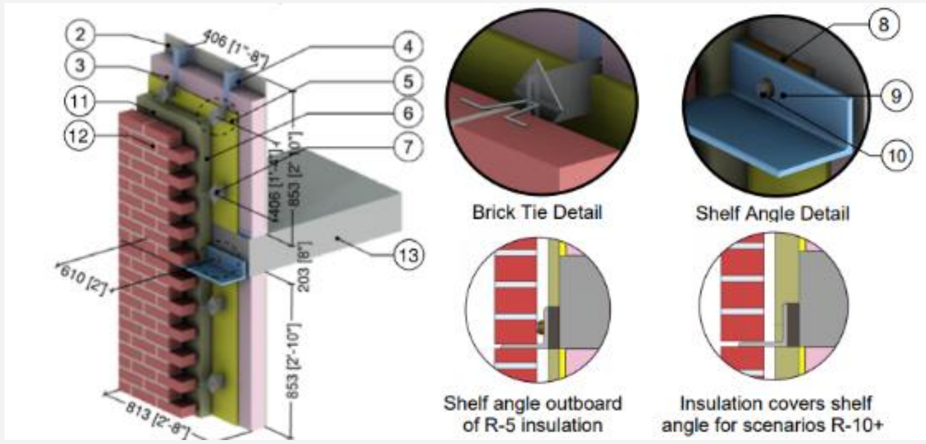
Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	12" Vertical Clip Spacing		16" Vertical Clip Spacing		24" Vertical Clip Spacing		36" Vertical Clip Spacing		42" Vertical Clip Spacing	
		R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft² ·hr ·°F (W/m² K)
R-8.4 (1.48)	R-11.7 (2.06)	R-9.6 (1.70)	0.104 (0.59)	R-9.9 (1.75)	0.101 (0.57)	R-10.4 (1.83)	0.096 (0.55)	R-10.9 (1.92)	0.092 (0.52)	R-11.0 (1.94)	0.091 (0.51)
R-16.8 (2.96)	R-20.1 (3.54)	R-14.3 (2.51)	0.070 (0.40)	R-15.1 (2.65)	0.066 (0.38)	R-16.4 (2.88)	0.061 (0.35)	R-17.6 (3.11)	0.057 (0.32)	R-18.0 (3.16)	0.056 (0.32)
R-25.2 (4.44)	R-28.5 (5.02)	R-18.8 (3.31)	0.053 (0.30)	R-20.1 (3.54)	0.050 (0.28)	R-22.2 (3.91)	0.045 (0.26)	R-24.3 (4.28)	0.041 (0.23)	R-24.8 (4.37)	0.040 (0.23)
R-33.6 (5.92)	R-36.9 (6.50)	R-21.3 (3.76)	0.047 (0.27)	R-22.7 (4.00)	0.044 (0.25)	R-25.3 (4.46)	0.039 (0.22)	R-28.9 (5.08)	0.035 (0.20)	R-30.5 (5.36)	0.033 (0.19)

Note how the Guide uses R_o and U_o to represent whole assembly values, after derating. This should not be confused with Section C402.7.2.1 where R_o represents continuous insulation before derating.

Interpolation between rows and column of the Thermal Data Sheet is allowed. Extrapolation is not allowed.

Example

A building project builds an assembly with brick panel sections matching Detail 5.2.49 (Material Data Sheet shown on right) having R-20 exterior continuous insulation. What is the whole assembly R and U?



Solution

The Thermal Data Sheet for Detail 5.2.49 is reproduced below. This particular pre-solved solution set includes the assembly R and U values with and without the derating effect of the brick shelf angle.

- If the designer decides to account for the effect of the brick shelf later in the derating process, the designer would use the R_o column (R_o=22.5) and U_o column (U_o=0.045) contained in the red circle for the derated value of the wall and account for the brick shelf as a linear thermal bridge (see next section).

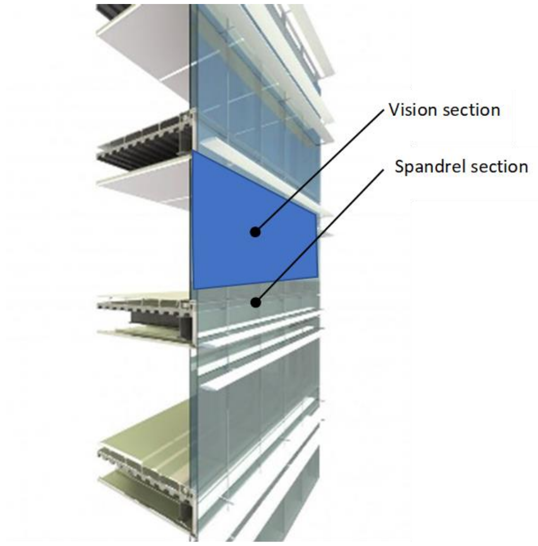
- If the designer decides to account for the effect of the brick shelf during this step of the derating process, the designer would use the R column (R-16.0) and U column (U-0.062) contained in the blue circle. If the brick shelf angle is included in this step, it would not have to be included as part of the linear thermal bridge derating step.

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-20.3 (3.58)	R-13.9 (2.45)	0.072 (0.41)	R-9.2 (1.62)	0.109 (0.62)	0.228 (0.394)
R-10 (1.76)	R-25.3 (4.46)	R-17.0 (3.00)	0.059 (0.33)	R-12.8 (2.26)	0.078 (0.44)	0.119 (0.206)
R-15 (2.64)	R-30.3 (5.34)	R-19.8 (3.48)	0.051 (0.29)	R-14.5 (2.55)	0.069 (0.39)	0.114 (0.198)
R-20 (3.52)	R-35.3 (6.22)	R-22.5 (3.96)	0.045 (0.25)	R-16.0 (2.82)	0.062 (0.35)	0.111 (0.193)
R-25 (4.40)	R-40.3 (7.10)	R-24.9 (4.38)	0.040 (0.23)	R-17.4 (3.07)	0.057 (0.33)	0.107 (0.185)

Temperature Indices

Spandrel Sections of Glazed Wall Systems



The spandrel section of a glazed wall systems (which is the opaque section of the glazed wall system) typically contains numerous metal connections which can create significant thermal bridges. The connections can be viewed as a kind of clear field thermal bridge.

Section C402.7.4 is a new code section specifically to address thermal performance within spandrel sections. This section mandates using either prescriptive thermal performance, pre-solved thermal performance, or modeled values to account for this clear field-like thermal bridge.

Prescriptive Compliance (C402.7.4.1)

To use prescriptive compliance, use Table C402.7.4.1. At least R-12 of insulation must be installed behind the spandrel to comply with this section.

Reference Compliance (C402.7.4.2)

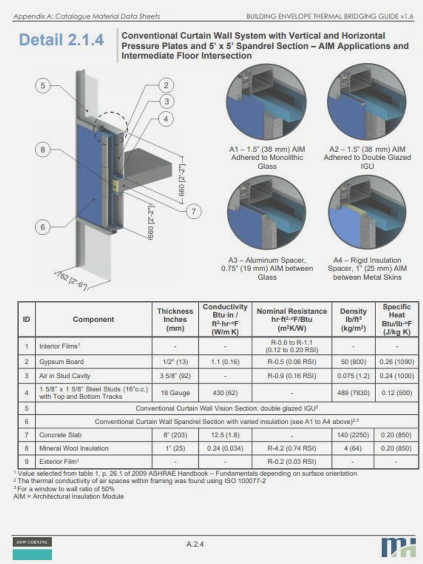
To use prescriptive compliance, use the pre-solved opaque spandrel sections R values contained in the Guide.

Example

A building project includes a spandrel section built to the materials and dimensions of Detail 2.1.4 using R-39.1 behind the spandrel. What is the spandrel thermal performance?

Solution

Detail 2.1.4 is reproduced to the right and thermal performance information is below. The thermal performance of the spandrel portion is under the R_s and U_s columns, shown in red circle. The thermal performance of this section after derating is R-7.1 and U-0.141.



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 Films[1]	-	-	R-0.6 to R-1.1 (0.12 to 0.20 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	1 5/8" x 1 5/8" Steel Studs (16"o.c.) with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Conventional Curtain Wall Vision Section: double glazed IGU[2]					
6	Conventional Curtain Wall Spandrel Section with varied insulation (see A1 to A4 above)[2,3]					
7	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Mineral Wool Insulation	1" (25)	0.24 (0.034)	R-4.2 (0.74 RSI)	4 (64)	0.20 (850)
9	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within framing was found using ISO 100077-2
[3] For a window to wall ratio of 50%
AIM = Architectural Insulation Module

A.2.4

Scenarios

Scenario	Vision Glass and Spacer	Insulation Thickness and Application	AIM Spacer/Edge Condition
A	Double Glazed with Aluminum Spacer	1.5" (38 mm) AIM adhered to Monolithic Glass	None
B	Double Glazed with Aluminum Spacer	1.5" (38 mm) AIM adhered to Insulating Glass	None
C	Double Glazed with Aluminum Spacer	0.75" (19 mm) AIM between Glass	Aluminum Spacer
D	Double Glazed with Aluminum Spacer	1" (25 mm) AIM between Metal Skins	Rigid Insulation

Nominal (1D) vs. Assembly Performance Indicators

Scenario	Insulation R-Value (RSI)	R_s ft²·hr·°F / Btu (m² K / W)	U_s Btu/ft² ·hr ·°F (W/m² K)	R_g ft²·hr·°F / Btu (m² K / W)	U_g Btu/ft² ·hr ·°F (W/m² K)	R_t ft²·hr·°F / Btu (m² K / W)	U_t[1] Btu/ft² ·hr ·°F (W/m² K)
A	R-58.6 (10.32)	R-6.1 (1.08)	0.163 (0.93)	R-2.3 (0.41)	0.427 (2.42)	R-3.4 (0.60)	0.295 (1.68)
B	R-58.6 (10.32)	R-6.3 (1.10)	0.160 (0.91)	R-2.4 (0.42)	0.416 (2.36)	R-3.5 (0.61)	0.288 (1.64)
C	R-29.3 (5.16)	R-6.4 (1.12)	0.157 (0.89)	R-2.4 (0.42)	0.422 (2.40)	R-3.5 (0.61)	0.289 (1.64)
D	R-39.1 (6.89)	R-7.1 (1.25)	0.141 (0.80)	R-2.4 (0.42)	0.417 (2.37)	R-3.6 (0.63)	0.279 (1.58)

Linear Thermal Bridges

Section C402.7.3 requires that, in addition to clear field derating, walls shall be further derated for eight specific linear thermal bridges (Thermal Bridges 4 through 11) using Equation C402.7.3.

$$U_{derated} = \frac{PSI * length}{A_{total}} + U_o$$

The example below presents the overall process for this part of the derating process.

Example

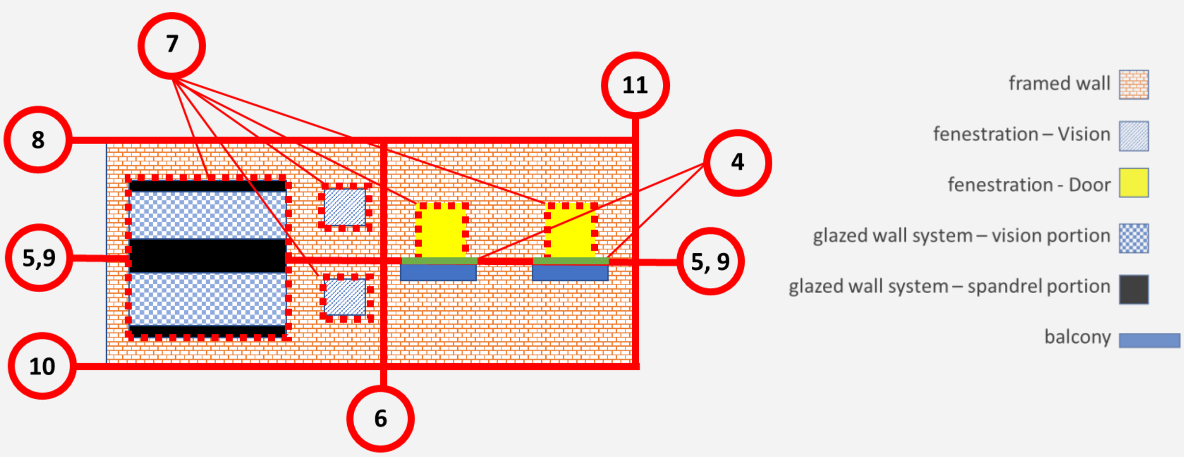
A building project includes a south elevation (shown below) using a framed wall assembly having brick panel sections matching Detail 5.2.49 using R-20 exterior continuous insulation. As shown above, when accounting for clear field thermal bridges, this brick wall assembly has a derated R_o value of R_o-22.5 and U_o value of U_o-0.045. Note that R and U values without the effect of the brick shelf angle is used and thus the brick shelf angle must now be included as a linear thermal bridge.

The south elevation also includes a glazed wall system with a spandrel portion having an R value of R-10 and U value of U-0.100.

What are the R and U values of walls after accounting for linear Thermal Bridges 4 through 11? Use the prescriptive thermal bridge PSI-values contained in Table C402.7.3.1.

Solution

The first step is to identify Thermal Bridges 4 through 12 and the length of each (see below).



South elevation

The table below summarizes each linear thermal bridge (Thermal Bridge 4 through 11), one row for each, the prescriptive PSI value, and the length.

When calculating lengths be sure not to double count linear thermal bridges. For example, in the pre-solved solutions, the balcony linear thermal bridge (Thermal Bridge Number 4) PSI value already includes the effect of the adjacent floor/vertical wall intersection (Thermal Bridge Number 5). Therefore, when estimating the length of Thermal Bridge Number 5, do not include the balcony lengths. The note column describes how each length was calculated.

.	Description	PSI Value (Btu/hr-ft-F)	Length (ft)	PSI x Length (Btu/hr-F)	Notes
4	Balcony to exterior wall intersection	1.00	10	10	Each balcony 5-ft wide
5	Intermediate floor to exterior vertical wall intersection	0.60	65	39	Do not count length where floor intersects balcony and glazed wall systems. Calculated as: Width of elevation (100-ft) minus total width of balcony (10-ft) minus width of glazed wall system (25-ft)
6	Intertior vertical wall to exterior vertical wall intersection	0.50	20	10	Height of elevation (20-ft)
7	Fenestration to exterior vertical wall intersection	0.32	136	44	Total length of red dashed lines around doors, windows, and exterior of glazed wall system. Note - do not inlcude bottom of doors where they meet balcony. Calculated as: perimeter of glazed wall system (25+25+16+16) plus perimeter of two windows (3+3+3+3)*2 plus sides and top of two doors (6+3+6)*2
8	Parapet (vertical wall to roof intersection)	0.60	100	60	Width of elevation (100-ft)
9	Brick shelf angle	0.35	75	26	Effect of brick shelf angle is not included in clear field value for brick wall assembly, therefore the effect must be included here. Calculated as: one brick shelf per floor (1) times width of elevetion (100-ft) minus width of glazed wall system (25-ft).
10	Vertical wall to grade intersection	0.52	100	52	Width of elevation (100-ft)
11	Vertical wall plane transition (building corners and other changes in vertical wall plane)	0.25	20	5	Height of elevation (20-ft). Count one corner per elevation.
			Total	**246**	**Btu/hr-F**

Multiply the PSI values by the lengths, then sum to obtain 246 Btu/hr-F which represents a **heat loss rate** for linear thermal bridges.

Next, calculate wall area of the elevation, as follows:

total elevation area	2,000-sf	(width of elevation times height of elevation)
less door fenestration	(36-sf)	(area of door (3x6) times number of doors)
less window fenestration	(18-sf)	(area of window (3x3) times number of windows)
less vision section of glazed wall system	(300-sf)	(area of vision (6x25) times number of vision areas)
Opaque area:	1,646-sf	

Divide the heat loss rate above (246 Btu/hr-F) by this area (1,646-sf) to obtain the **normalized heat loss rate** of 0.15 Btu/hr-F-sf**.** Note that this has the same units a U-value. The normalized heat loss rate is added to the assembly U value account for the effect of linear thermal bridges, as follows:

For the brick assembly

Assembly U value:	U-0.045 Btu/hr-F-sf	(Assembly U derated for clear field)
Add normalized heat loss rate:	U-0.15 Btu/hr-F-sf	(Heat loss due to linear)
New assembly U value:	U-0.19 Btu/hr-F-sf	(Derated for both clear field and linear)

Accordingly, the assembly U-value and R-value, accounting for both clear field and linear thermal bridges is as follows:

U-value	U-0.19 Btu/hr-F-sf
R-value	R-5.16 hr-F-sf/Btu

For the opaque, spandrel section of the *glazed wall system*

Assembly U value:	U-0.10 Btu/hr-F-sf	(Assembly U derated for clear field)
Add normalized heat loss rate:	U-0.15 Btu/hr-F-sf	(Heat loss due to linear)
New assembly U value:	U-0.25 Btu/hr-F-sf	(Derated for both clear field and linear)

Accordingly, the assembly U-value and R-value, accounting for both clear field and linear thermal bridges is as follows:

U-value	U-0.25 Btu/hr-F-sf
R-value	R-4.01 hr-F-sf/Btu

In the above example, the calculation is performed across one of the building elevations (the south elevation), resulting in a normalized heat loss rate which then is applied to all opaque wall assemblies comprising the south elevation. This process would be independently repeated for all other elevations. Each elevation would have its own normalized heat loss rate to be applied across the opaque wall assemblies comprising each elevation.

As can be seen from the example, the effect of linear thermal bridges is significant. In the above example, prescriptive PSI values from Table 403.7.2.1 were used for all linear thermal bridges. These prescriptive PSI values are based on details which have no thermal bridge mitigation.

The next example presents the same example as above, but using details which do incorporate robust thermal bridge mitigation strategies.

Example

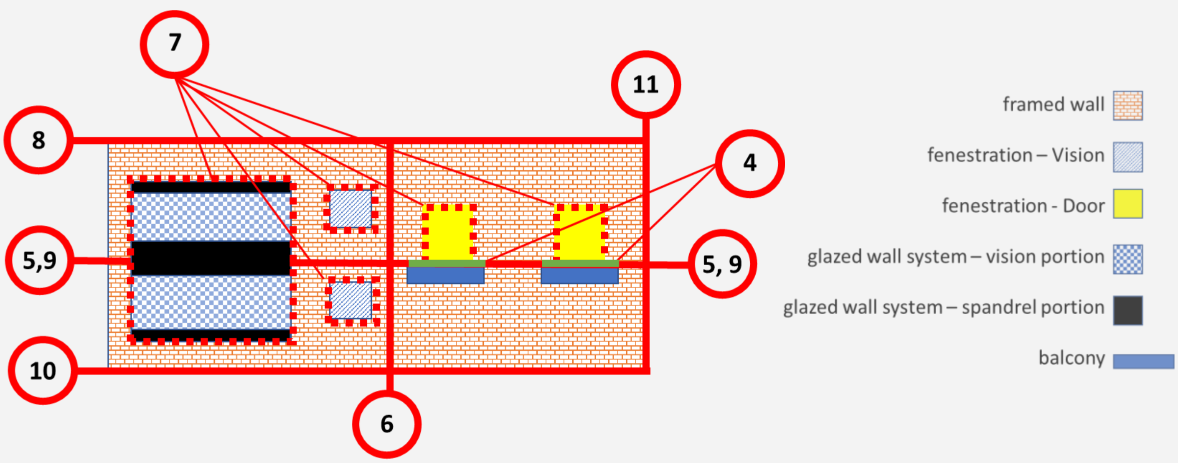
A building project includes a south elevation (shown below) using a framed wall assembly having brick panel sections matching Detail 5.2.49 using R-20 exterior continuous insulation. When accounting for clear field thermal bridges, this brick wall assembly has a derated R_o value of R_o-22.5 and U_o value of U_o-0.045. Note that R and U values without the effect of the brick shelf angle is used and thus the brick shelf angle must now be included as a linear thermal bridge.

The south elevation also includes a glazed wall system with a spandrel section having an R value of R-10 and U value of U-0.100.

What are the R and U values of the framed wall assembly and spandrel section of the glazed wall assembly after accounting for linear Thermal Bridges 4 through 11? Use details available in the Guide which have thermal mitigation.

Solution

Calculation of the lengths of thermal bridges remains the same as the above example.



South elevation

The table below presents the lengths and PSI values as well as the Guide assembly number for assemblies which use more robust thermal bridge mitigation strategies.

TB No.	Description	PSI Value (Btu/hr-ft-F)	Length (ft)	PSI x Length (Btu/hr-F)	Thermal Bridge Detail Number
4	Balcony to exterior wall intersection	0.098	10	1	9.1.11
5	Intermediate floor to exterior vertical wall intersection	0.135	65	9	5.2.29
6	Intertior vertical wall to exterior vertical wall intersection	0.262	20	5	7.2.3
7	Fenestration to exterior vertical wall intersection	0.051	136	7	7.3.15
8	Parapet (vertical wall to roof intersection)	0.112	100	11	5.5.16
9	Brick shelf angle	0.111	75	8	5.2.49
10	Vertical wall to grade intersection	0.231	100	23	7.7.10
11	Vertical wall plane transition (building corners and other changes in vertical wall plane)	0.016	20	0	8.5.2
			Total	**65**	**Btu/hr-F**

Multiply the PSI values by the lengths, then sum to obtain 65 Btu/hr-F which represents a **heat loss rate** for linear thermal bridges. Note that this heat loss rate is more than 70% smaller than the previous example which uses details with no thermal bridge mitigation strategies.

The opaque wall area calculation is unchanged from previous example:

total elevation area	2,000-sf	(width of elevation times height of elevation)
less door fenestration	(36-sf)	(area of door (3x6) times number of doors)
less window fenestration	(18-sf)	(area of window (3x3) times number of windows)
less vision section of glazed wall system	(300-sf)	(area of vision (6x25) times number of vision areas)
Opaque area:	1,646-sf	

Divide the heat loss rate above (65 Btu/hr-F) by this area (1,646-sf) to obtain the **normalized heat loss rate** of 0.0394 Btu/hr-F-sf**.** Note that this has the same units a U-value. The normalized heat loss rate is added to the assembly U value account for the effect of linear thermal bridges, as follows:

For the brick assembly

Assembly U value:	U-0.045 Btu/hr-F-sf	(Assembly U derated for clear field)
Add normalized heat loss rate:	U-0.0394 Btu/hr-F-sf	(Heat loss due to linear)
New assembly U value:	U-0.0844 Btu/hr-F-sf	(Derated for both clear field and linear)

Accordingly, the assembly U-value and R-value, accounting for both clear field and linear thermal bridges is as follows:

U-value	U-0.0844 Btu/hr-F-sf
R-value	R-11.8 hr-F-sf/Btu

For the opaque, spandrel section of the *glazed wall system*

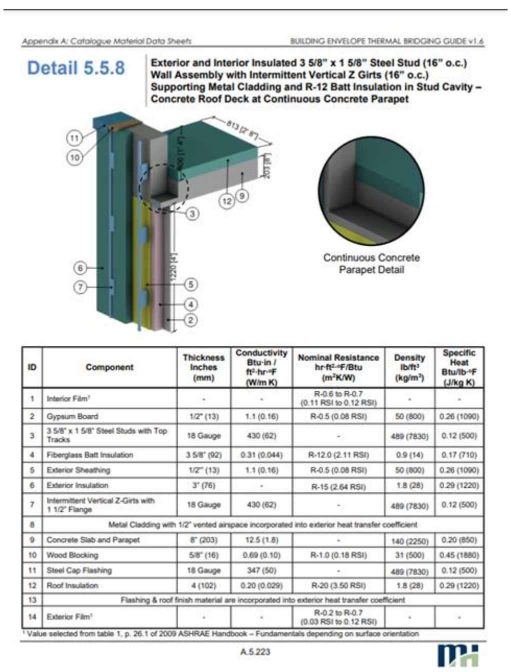
Assembly U value:	U-0.10 Btu/hr-F-sf	(Assembly U derated for clear field)
Add normalized heat loss rate:	U-0.0394 Btu/hr-F-sf	(Heat loss due to linear)
New assembly U value:	U-0.1394 Btu/hr-F-sf	(Derated for both clear field and linear)

Accordingly, the assembly U-value and R-value, accounting for both clear field and linear thermal bridges is as follows:

U-value	U-0.14 Btu/hr-F-sf
R-value	R-7.17 hr-F-sf/Btu

The above example demonstrates that with robust thermal mitigation, the effect of linear thermal bridges is still significant but the impact can be mitigated.

The PSI values for linear thermal bridges are readily obtainable in the Guide. For example, for parapet assembly Detail 5.5.8, the PSI value is 0.396 Btu/ft-hr-F, circled below.



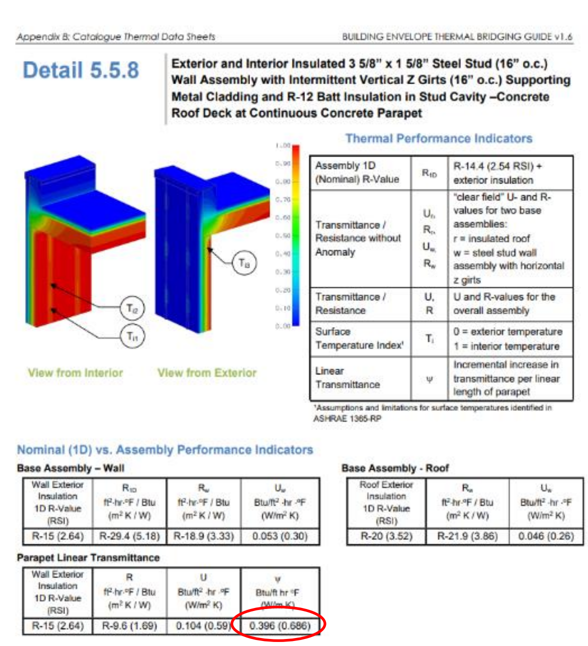
Appendix A: Catalogue Material Data Sheets BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 5.5.8 **Exterior and Interior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Wall Assembly with Intermittent Vertical Z Girts (16" o.c.) Supporting Metal Cladding and R-12 Batt Insulation in Stud Cavity – Concrete Roof Deck at Continuous Concrete Parapet**

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[1]	-	-	R-0.6 to R-0.7 (0.11 RSI to 0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs with Top Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Fiberglass Batt Insulation	3 5/8" (92)	0.31 (0.044)	R-12.0 (2.11 RSI)	0.9 (14)	0.17 (710)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Exterior Insulation	3" (76)	-	R-15 (2.64 RSI)	1.8 (28)	0.29 (1220)
7	Intermittent Vertical Z-Girts with 1 1/2" Flange	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient					
9	Concrete Slab and Parapet	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
10	Wood Blocking	5/8" (16)	0.69 (0.10)	R-1.0 (0.18 RSI)	31 (500)	0.45 (1880)
11	Steel Cap Flashing	18 Gauge	347 (50)	-	489 (7830)	0.12 (500)
12	Roof Insulation	4 (102)	0.20 (0.029)	R-20 (3.50 RSI)	1.8 (28)	0.29 (1220)
13	Flashing & roof finish material are incorporated into exterior heat transfer coefficient					
14	Exterior Film[1]	-	-	R-0.2 to R-0.7 (0.03 RSI to 0.12 RSI)	-	-

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

A.5.223



Appendix B: Catalogue Thermal Data Sheets BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 5.5.8 **Exterior and Interior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Wall Assembly with Intermittent Vertical Z Girts (16" o.c.) Supporting Metal Cladding and R-12 Batt Insulation in Stud Cavity –Concrete Roof Deck at Continuous Concrete Parapet**

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-14.4 (2.54 RSI) + exterior insulation
Transmittance / Resistance without Anomaly	U_r, R_r, U_w, R_w	"clear field" U- and R-values for two base assemblies: r = insulated roof w = steel stud wall assembly with horizontal z girts
Transmittance / Resistance	U, R	U and R-values for the overall assembly
Surface Temperature Index[1]	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of parapet

[1]Assumptions and limitations for surface temperatures identified in ASHRAE 1365-RP

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Wall Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_w ft²·hr·°F / Btu (m² K / W)	U_w Btu/ft² ·hr ·°F (W/m² K)
R-15 (2.64)	R-29.4 (5.18)	R-18.9 (3.33)	0.053 (0.30)

Base Assembly - Roof

Roof Exterior Insulation 1D R-Value (RSI)	R_w ft²·hr·°F / Btu (m² K / W)	U_w Btu/ft² ·hr ·°F (W/m² K)
R-20 (3.52)	R-21.9 (3.86)	0.046 (0.26)

Parapet Linear Transmittance

Wall Exterior Insulation 1D R-Value (RSI)	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-15 (2.64)	R-9.6 (1.69)	0.104 (0.59)	0.396 (0.686)

Modeled Derating

A finite element heat transfer model can be used to develop derated U-values. Because nearly all assemblies have point thermal bridges or thermal bridging in multiple planes, three-dimensional modeling is typically necessary. This is particularly true for spandrel sections of *glazed wall systems*. Models should be performed by a licensed engineer experienced in heat transfer through building assemblies and the results should be stamped by a professional engineer. Model results should be accompanied with supporting calculations, drawings, and details uniquely developed for the subject project.

Showing Compliance with Minimum Allowable Envelope Performance

As noted above, there are two choices to showing compliance with minimum allowable envelope performance. To review:

- "Prescriptive compliance" (C402.1.4). With this approach, each opaque and vision element needs to individually meet or exceed specified performance factors and the vision areas cannot exceed set limits in C402.4.

- "Flexible compliance" (C402.1.5). With this approach, with one exception, the performance factors AND vision areas of the above-grade *vertical* elements are flexible, so long as overall above-grade vertical performance meets certain standards. The exception is: any vision sections within a *glazed wall system* must meet certain performance factors. Horizontal and below-grade elements still need to individually meet or exceed specified performance factors and horizontal vision elements (e.g. skylights) must be within specified areas.

When showing compliance with minimum allowable envelope performance, use assembly performance values derated for both clear field and linear thermal bridges. The next two sections provide a summary of this process.

Process for Prescriptive Compliance (C402.1.4)

When using prescriptive compliance (C402.1.4), use the process below, repeating the process as necessary opaque assemblies meet the U-value in C402.1.4. Vision component U-values must meet C402.4.

Step 1: Create tables of linear thermal bridges 4 through 11 for each wall elevation to calculate the total normalized heat loss rate. (Section C402.7.3).

Step 2: Identify each distinct assembly (framed walls with rainscreen, masonry walls with rainscreen, framed walls with brick, window, etc).

Step 3: Derate each opaque wall assembly for clear field thermal bridges (Section C402.7.2).

Step 4: Further derate each opaque wall assembly for linear thermal bridges by adding the total normalized heat loss rate from Step 1 to results in Step 3.

Step 5: Confirm that opaque assemblies meet the U-factor requirements of Section C402.1.4 and the vision components meet the requirements of Section C402.4

Process for Flexible Compliance (C402.1.5)

When using flexible compliance (C402.1.5), use the process below, repeating the process as necessary until the area-weighted U-value has maximum of either U-0.1285 or U-0.1600 per C402.1.5.

Step 1: Create tables of linear thermal bridges 4 through 11 for each wall elevation to calculate the total normalized heat loss rate. (Section C402.7.3).

Step 2: Identify each distinct assembly (framed walls with rainscreen, masonry walls with rainscreen, framed walls with brick, window, spandrel sections of glazed wall systems, vision section of opaque wall system, etc).

Step 3: Derate each opaque wall assembly for clear field thermal bridges (Section C402.7.2).

Step 4: Obtain U-value for spandrel sections of glazed wall systems (Section C402.7.4).

Step 5: Further derate each opaque wall and spandrel sections for linear thermal bridges by adding the total normalized heat loss rate from Step 1 to results in Step 3 and 4.

Step 6: Calculate area-weighted U for the vertical assemblies and confirm that the area weighted U-factor meets the requirements of Section C402.1.5.