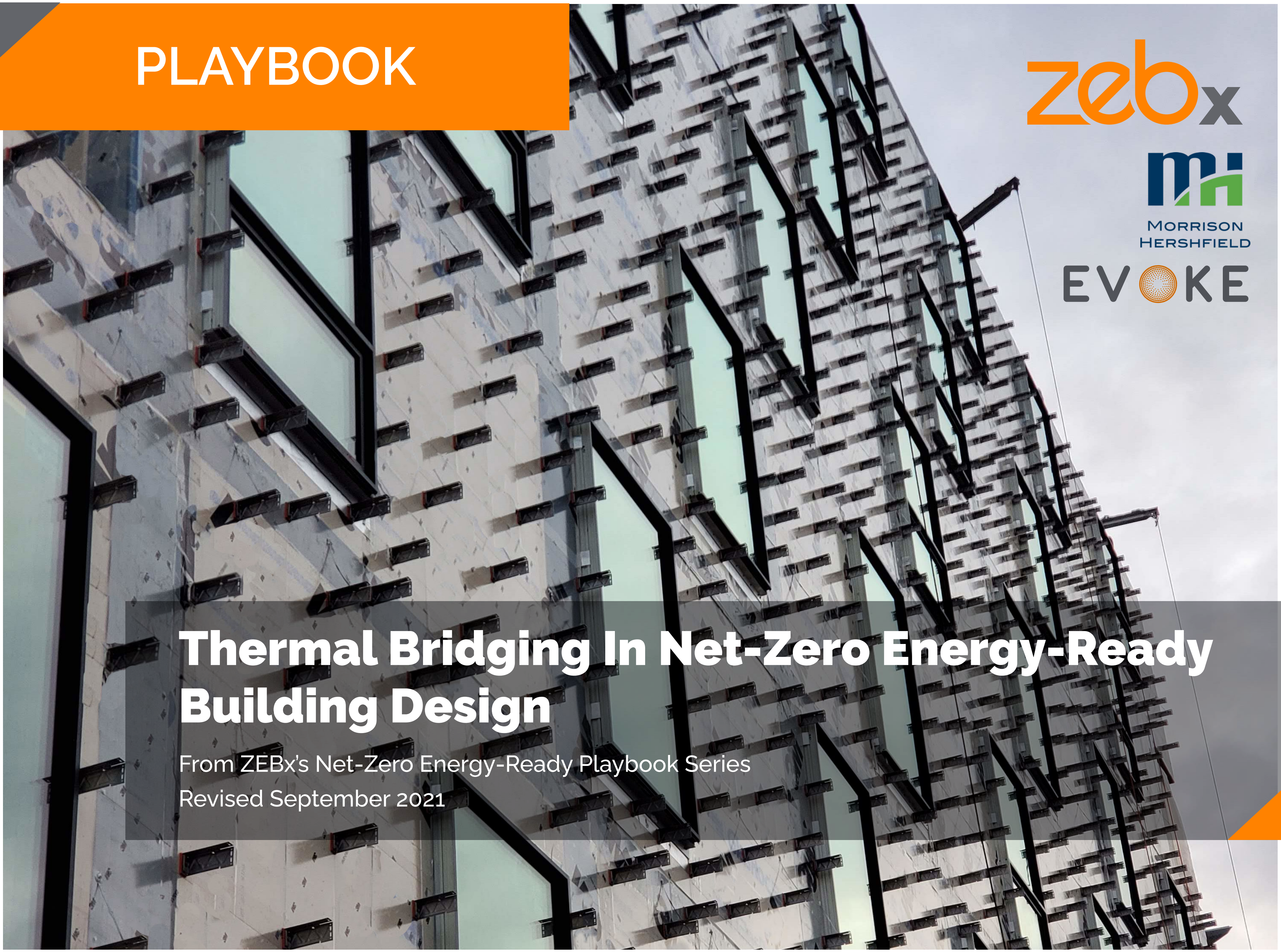
PLAYBOOK



Thermal Bridging In Net-Zero Energy-Ready Building Design

From ZEBx's Net-Zero Energy-Ready Playbook Series

Revised September 2021

Overview

Minimizing thermal bridging through the building envelope is a key design aspect for achieving net-zero energy-ready (NZER) buildings. However, this can seem quite complicated for project teams, especially when much of the envelope is unknown during the early building design stage.

Finding the optimal envelope solution for thermal performance that also incorporates architectural intent, cost savings, constructibility and durability is only achieved when the entire project team is engaged to collectively meet these goals.

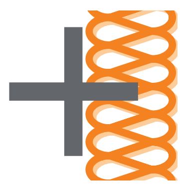
This playbook outlines good design practices for anticipating and dealing with thermal bridging in order to meet the expectations of the BC Energy [Step Code], Passive House or other NZER standards. The intent of this document is to provide guidance for design teams including developers, architects and consultants, to effectively tackle thermal bridging while meeting all project goals, not just thermal performance.

All R-value units are presented in $ft^2 \cdot hr \cdot F/Btu$.

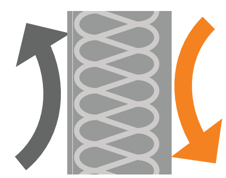
This playbook provides high level design guidance and assumes the reader has a basic knowledge of building envelope thermal performance metrics, such as U-values, effective R-values and linear transmittances. For more information specifically on conducting thermal bridging calculations and envelope thermal values, please see the **Building Envelope Thermal Bridging Guide** at www.thermalenvelope.ca

Penetrations through the envelope for canopy supports create thermal bridging

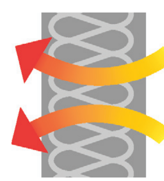
Building envelopes suitable to meet thermal energy demand intensity (TEDI) targets and thermal comfort expectations in NZER designs require significant improvements to standard design decisions[1], most notably:



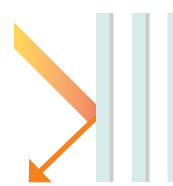
More insulation



Increased airtightness



Thermal bridging mitigation



High performance glazing

Mitigating Thermal Bridging

Why Thermal Bridging Matters

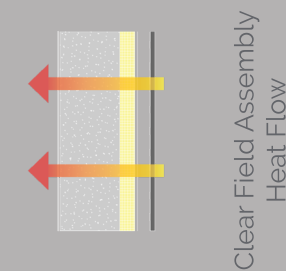
In order to appropriately address thermal bridging on NZER projects, designers and owners need to understand its importance and why it cannot be ignored. Thermal bridging is important for two main reasons.

1. **Environmental Impacts:** Thermal bridging impacts energy consumption, design of HVAC systems, condensation control, occupant comfort, and embodied carbon.

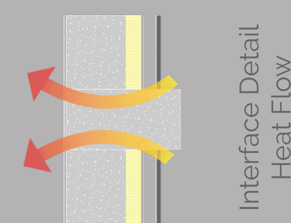
2. **Regulatory Requirements**: Comprehensive thermal bridging calculations are required progressive energy codes and NZER standards. Not adequately addressing thermal bridging can impose constraints on other design aspects, including architectural features, window-to-wall ratios, heat recovery efficiency, air tightness requirements, insulation thickness, glazing transmittance, and options for heating and cooling systems.

Thermal Bridging and Interface Details

Thermal bridging occurs when structural framing and other conductive components bypass the insulation, increasing heat flow through the building envelope. Repetitive thermal bridging, such as cladding attachments, studs, brick ties, are included in **clear field assemblies** and consequently, in the clear field wall assembly's thermal transmittance value (U_o). Clear field assemblies consist of uniformly distributed thermal bridges, which are not practical to account for on an individual basis. Examples include wall assemblies, roof assemblies and floor assemblies.



Thermal bridging that occurs between assemblies are called **interface details**. Interface details interrupt the clear field assemblies where there are changes in the construction type, materials or geometry. Examples include intermediate floors, roof-to-wall interfaces, window-to-wall interfaces, corners, and at-grade interfaces. The additional heat flow as a result of these interfaces is accounted for by linear and point transmittances. These transmittance values are typically found later in the detail sheets on architectural drawings.



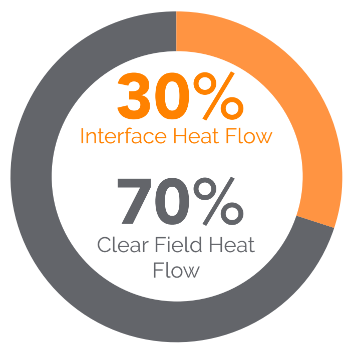
Mitigation: How Much is Good Enough?

Each thermal bridge contributes to the overall heat flow through the envelope. To minimize their impacts and to comply with energy codes, all thermal bridging needs to be viewed holistically. In this regard, two important principles should be remembered:

> **Thermal bridging cannot be totally eliminated, only mitigated.** Understanding this will help designers avoid overly complicated solutions to mitigate the impact of thermal bridging.
>
> **A more stringent energy-performance target will necessitate greater mitigation of thermal bridging at interface details.** For NZER projects, aiming for continuous insulation in clear field assemblies is not enough to control thermal bridging. If interface details are left unmitigated, thermal bridging could easily account for more than 60% of the total heat flow through the opaque envelope[2]. This amount of heat loss could negate any improvements made to clear field assemblies.

With these principles in mind, the best approach for mitigating thermal bridging is to determine each interface detail's contribution to the total heat flow, which varies depending on the type of building and construction. Having this information will allow design teams to tackle the right details that have the greatest impact.

If not addressed in the early design stage, thermal bridging at interface details can be a significant proportion of the heat flow through the building envelope.



A preliminary target for effectively mitigating thermal bridging is to keep the total heat flow contribution from interface details to **30%**. This is a reasonable starting point for most Part 3 buildings aiming for the upper steps of the Step Code.

Where to Focus in Design

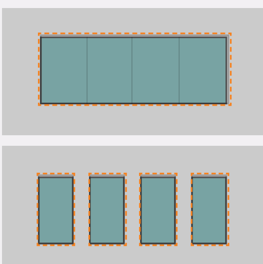
A simple building form and design goes a long way in reducing the envelope area and thermal bridging[1]. While mitigation is easier if the detail is absent to begin with, this is unrealistic for some projects and can limit architectural expression.

For many, the first detail they may be drawn to are **cantilevered concrete balconies.** They feature prominently on residential buildings, which invites attention and discussion. However, if balconies make up a relatively small percentage of the building perimeter (< 20%), other details will likely have a bigger influence on the thermal performance of the opaque building envelope.

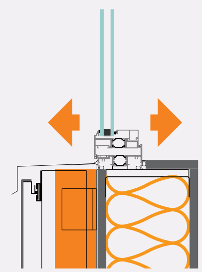
Window-to-wall interfaces are an often overlooked detail, but have a big impact on thermal bridging. While not as obvious as balconies, they often have a bigger impact. Window perimeters can add up to a significant length on a building. Even when there is minimal thermal bridging per window, the total linear transmittance around all the windows can be significant. A focus on window-to-wall interfaces can provide opportunities for large gains in performance, regardless of the type of building or construction.

For most projects, the primary focus for thermal bridging mitigation should be the window-to-wall interface. The priority for other thermal bridging mitigation will depend on the type of building and construction. On high-rise buildings, this will likely be the **intermediate floor** while, the **at-grade** and **roof-to-wall interfaces** will contribute more in low-rise buildings.

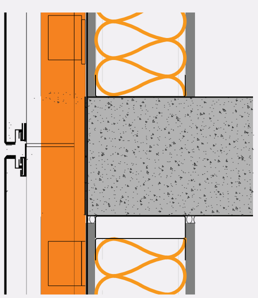
Top areas of focus to reduce thermal bridging in mid-rise and high-rise residential construction



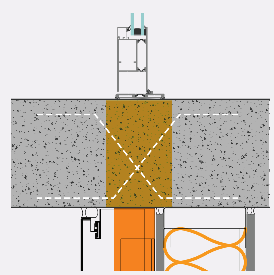
Reduce the total length of the window perimeters. This can be achieved by reducing linear quantity of interface by using larger glazed openings in lieu of multiple small openings.



Align the thermal break and insulated glass unit in the frame of the glazing with the insulation around the glazed opening. This may mean installing windows outboard of the structure for exterior-insulated assemblies. From a thermal bridging perspective, installing glazing on a support angle is better than directly on a steel-framed wall.



Ensure intermediate floors are insulated at every building level. Exterior insulation allows the edge of floor to be insulated. Mitigate thermal bridging at shelf angles, cladding attachments and flashing.



Avoid balconies or floor slab projections through the envelope that bypasses the thermal insulation. If large balconies are intended to be a defining architectural feature, consider thermally broken or point connected attachment systems.

Integrating Mitigation into Design

The Thermal Bridging Calculation Process

Determining the project-specific impacts of various thermal bridging details in a design starts with this simple three step process[3].

1. **Identify and make estimates for the clear field, linear, and point transmittances.**
2. **Perform a quantity takeoff of all clear field, linear, and point assemblies.**
3. **Multiply the thermal transmittances by the corresponding quantities to determine heat flow contributions, then add up the totals for the overall thermal transmittance.**

What is An Efficient Detail?

In the past, when thermal bridging was largely overlooked, many conventional buildings were constructed with interface details of *poor* to *moderate* thermal quality. As we move towards NZER building codes, better performance is needed to meet performance requirements.

Mitigated interface details may be adequate for current performance targets, but thermally efficient interface details will be required for NZER building design. Often, a linear transmittance less than 0.05 W/m•K is necessary for the window-to-wall interface to minimize the wall insulation thickness.

	Linear Transmittance	
	BTU/hr•ft•F	W/m•K
Thermal Bridge Free	< 0.01	< 0.01
Efficient	0.06	0.10
Mitigated	0.12	0.20
Moderate	0.17	0.30
Regular - Poor	> 0.23	> 0.30

Schematic Design Phase

1. **Determine Initial Envelope U-Value Targets**
Use a pre-screening tool, preliminary energy model to determine realistic initial targets for the overall vertical wall assemblies and opaque assemblies such as roof and floor assemblies.

2. **Determine Wall U-value Targets**
Estimate initial targets for the wall assemblies based on the overall envelope targets. Determine an allowance for thermal bridging through interface details.

Detailed Design Phase

3. **Conduct Thermal Bridging Calculations**
Determine transmittances starting with window-to-wall interfaces. In schematic design, conservative estimates should be used and refined during later design stages.

4. **Determine Impact**
Identify which details have the biggest impact.

5. **Tackle High Impact Details**
Refine assumptions and re-evaluate insulation thickness and/or design approach. Be mindful of other considerations such as costs, comfort and constructibility.

6. **Confirm Approach**
Confirm the suitability of the mitigation approach with the design team. If the mitigation approach is not acceptable, refine assumptions, project targets or reassess with a different approach.

R-10

Repeat until all goals are met

Thermal bridging calculations are only one part of the building envelope design requirements. It is important to keep looking for the details where mitigation will have the biggest impact, not only from the perspective of thermal efficiency, but also other equally important factors, such as durability, constructibility, and costs. This is an iterative process where assumptions and calculations are refined as the design progresses.

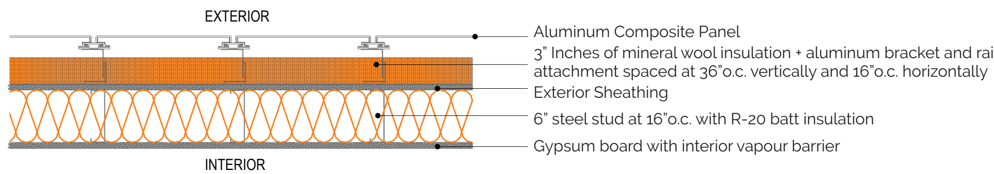
> *Many free industry tools are available to assist in this process. These tools can make completing calculations straightforward and facilitate refinements as the project progresses. Please see the references at the end of this playbook for links and resources.*

Putting Mitigation into Practice: A Mid-Rise Residential Example

The example building utilizes a concrete structure with steel framed walls. The window-to-wall ratio is 40% and the balconies comprise 20% of the above-grade intermediate floor perimeter. The exterior walls are split-insulated assemblies with composite aluminum cladding supported by an intermittent cladding attachment system.

This example outlines several design scenarios and their effective R-values. The scenarios start with conventional detailing, and show the incremental impact of different mitigating strategies to increase performance.

Each scenario includes the critical thermal bridging details for this type of building construction, as noted in the adjacent diagram, along with their relative contributions to the overall heat flow.



Example Mid-Rise R-21 (RSI 3.75) Clear Wall Assembly

The following formula provides an estimation for a thermal transmittance target during early design when there may be an overall envelope target, but specific details are not known.

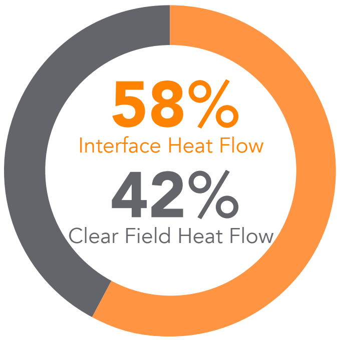
$$R_o = R / (1-x)$$

where
R_o = clear field R-value target
R = overall opaque envelope R-value
x = interface detail heat flow factor

It is recommended to use x = 0.5 as a conservative default value in early design to provide flexibility for optimization during detail design.

Example mid-rise interface details

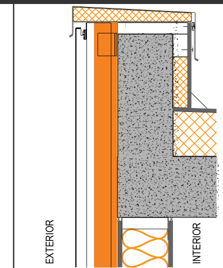
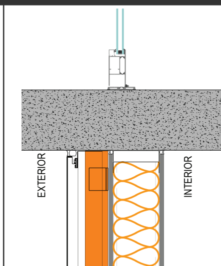
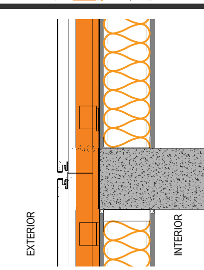
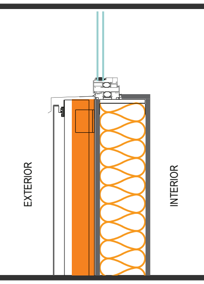
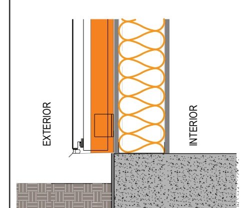
Scenario 1: Unmitigated thermal bridging at the interface details for an R-21 wall assembly



Effective R-value

Clear Field Wall Assembly	R-21
Overall	R-8.8

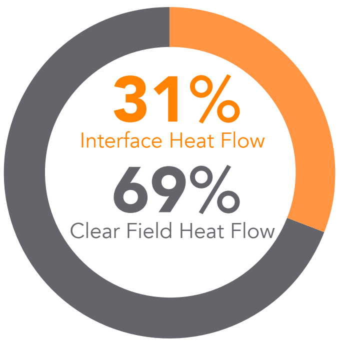
Proportion of heat flow / R-value units are in ft²·hr·F/Btu

Linear Transmittance	Distance	% Contribution to Overall heat flow	Details		
0.70 W/m·K	55 meters	7%		Roof-to-Wall	POOR
1.84 W/m·K	50 meters	18%		Balcony	POOR
0.11 W/m·K	220 meters	5%		Intermediate	MITIGATED
0.25 W/m·K	485 meters	23%		Window-to-wall	MODERATE
0.36 W/m·K	55 meters	4%		At-Grade	REGULAR

For this scenario, the interface details contribute almost 60% of the heat flow through the wall assembly, far more than through the main area of the wall.

These details represent fairly conventional design for low-rise multi-unit residential buildings in British Columbia.

Scenario 2: Mitigated thermal bridging at the interface details for an R-21 wall assembly



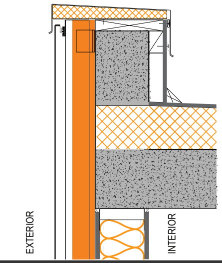
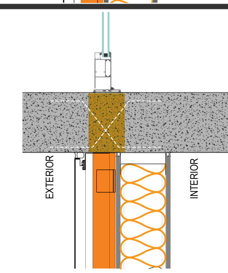
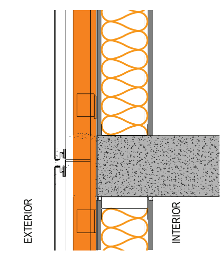
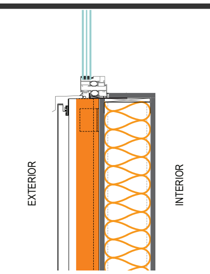
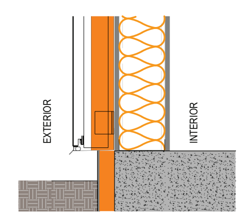
Effective R-value

Clear Field Wall Assembly **R-21**

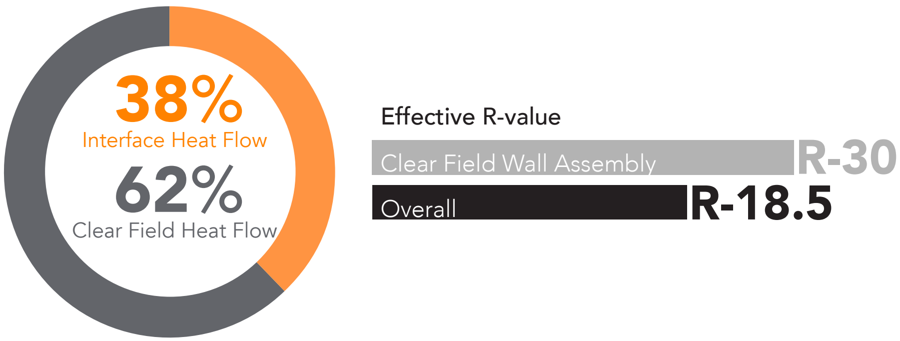
Overall **R-14.5**

Proportion of heat flow / R-value units are in ft²·hr·F/Btu

The previous scenario illustrated how the balconies and the window-to-wall interfaces were the most critical details. By improving these and the other details (as shown in the table), the overall thermal performance of the opaque wall assembly can be improved by 65%, without adding any insulation to the walls. The thermal bridging improvements in this scenario include a thermal break at the parapets and balconies, efficient window alignment and insulation under the slab-on-grade.

Linear Transmittance	Distance	% Contribution to Overall heat flow	Details		
0.18 W/m·K ↓74%	55 meters	3%		Roof-to-Wall	EFFICIENT
0.39 W/m·K ↓79%	50 meters	6%		Balcony	MODERATE
0.11 W/m·K	220 meters	5%		Intermediate	MITIGATED
0.08 W/m·K ↓68%	485 meters	12%		Window-to-wall	MITIGATED
0.05 W/m·K ↓86%	55 meters	1%		At-Grade	EFFICIENT

Scenario 3: Mitigated thermal bridging at the interface details for an R-30 wall assembly

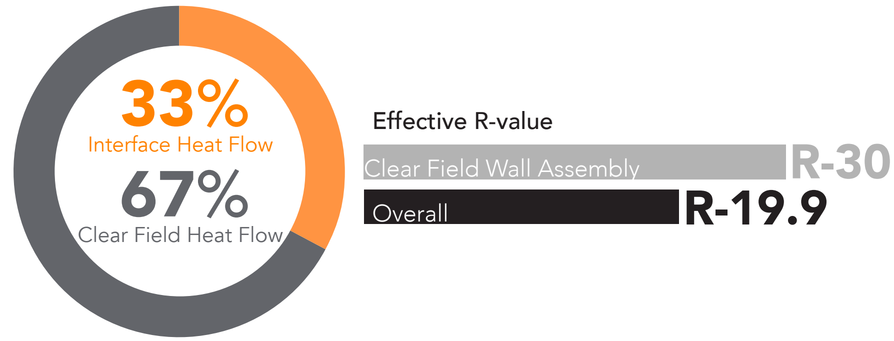


Proportion of heat flow | R-value units are in $ft^2 \cdot hr \cdot F/Btu$

Increasing the exterior mineral wool insulation thickness to 6" (152 mm) results in a clear field performance to R-30 (5.28 RSI). However, the overall effective R-value only increases to R-18.5 (3.26 RSI) with the same mitigated thermal bridging details in scenario 2. With this increase in thermal resistance of the clear field, the contribution of the interface details to the overall heat flow increases to 38%.

Another inch of insulation will push the overall effective R-value over R-20 (3.52 RSI) and will increase the contribution of the thermal bridging at the interface details to 40%.

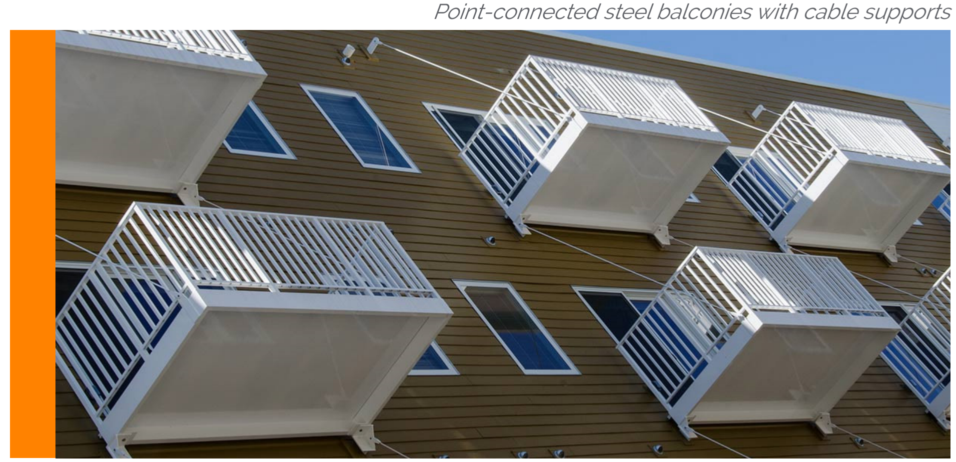
Scenario 4: Efficient Balcony Connections for an R-30 wall assembly



Proportion of Heat flow | R-value units are in $ft^2 \cdot hr \cdot F/Btu$

By adopting thermally efficient balcony connections, such as using a point-connected steel balcony with cable supports, an effective thermal resistance of R-20 can be achieved. Point-connected steel balconies reduce the overall thermal bridging to 33%.

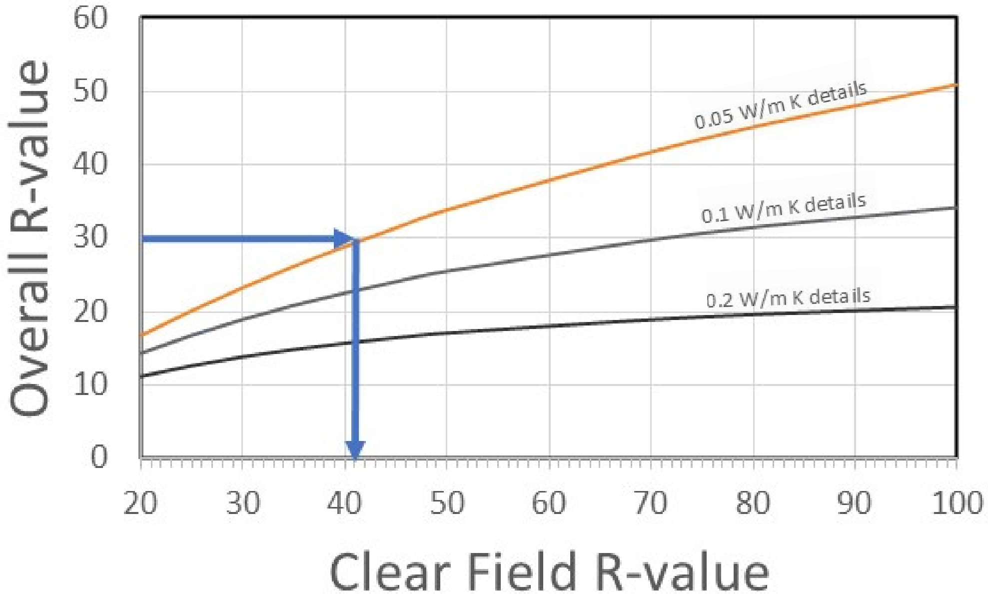
Point-connected steel balconies with cable supports



Achieving R-30+

Some NZER projects require building envelopes with thermal resistance exceeding R-30. To go beyond R-30 is possible, but it requires even more attention to minimizing thermal bridging.

Increasingly better details are required to meet a higher overall effective R-value because of diminishing returns associated with increasing insulation levels. If only more insulation is added, then the same or more heat will flow through the thermal bridging at interface details, making that insulation less effective.



Impact of average linear thermal bridging value on overall R-value

Passive House Wall Assembly

To achieve an overall effective R-30, more insulation and better thermal bridging mitigation is required. For example, if all combined interface details have a weighted average linear transmittance of 0.05 W/m·K (considered to be very efficient), R-30 can be achieved when used in-conjunction with a R-41 clear field wall assembly. In contrast, a clear field wall assembly of R-50 is required if the weighted average of the linear transmittance is 0.1 W/m·K (mitigated to efficient performance). The R-30 target is not achievable with linear transmittance averaging greater than 0.2 W/m·K (moderate or poor).

Performance-Based Specifications

Performance-based specifications are critical to allowing alternative approaches for key envelope systems that encourage cost-effective solutions and optimization, while maintaining the performance required to meet NZER targets. Performance-based specifications should be utilized not only for window and wall systems, but also for the interface between building envelope systems. Any contemplated alternatives can be reviewed for the impact on thermal bridging and adjacent systems.

Wall Performance

Secondary structural components to attach cladding such as thermal clips, brackets, rails and façade anchors, can be treated as point transmittances. Specifying a cladding attachment system using a point transmittance may seem like a viable approach. However, this approach does not adequately deal with how the layout of secondary structural component vary widely in practice, depending on the specific project requirements, sub-trade, cladding type and layout, and cladding attachment system. This approach can also make objectively assessing innovative approaches difficult, approaches that reduce thermal bridging and do not rely on closely spaced repetitive structural components. A better approach is to:

1. Specify a maximum U-value for the clear field wall assembly that includes the cladding attachment system.
2. Request documentation that outlines the proposed, site-specific cladding attachment system (including spacing and installation method).

Not only will this approach better reflect the as-built conditions, but it also permits a greater range of alternative, cost-effective solutions and the exploration of optimization opportunities to reduce the overall wall thickness.

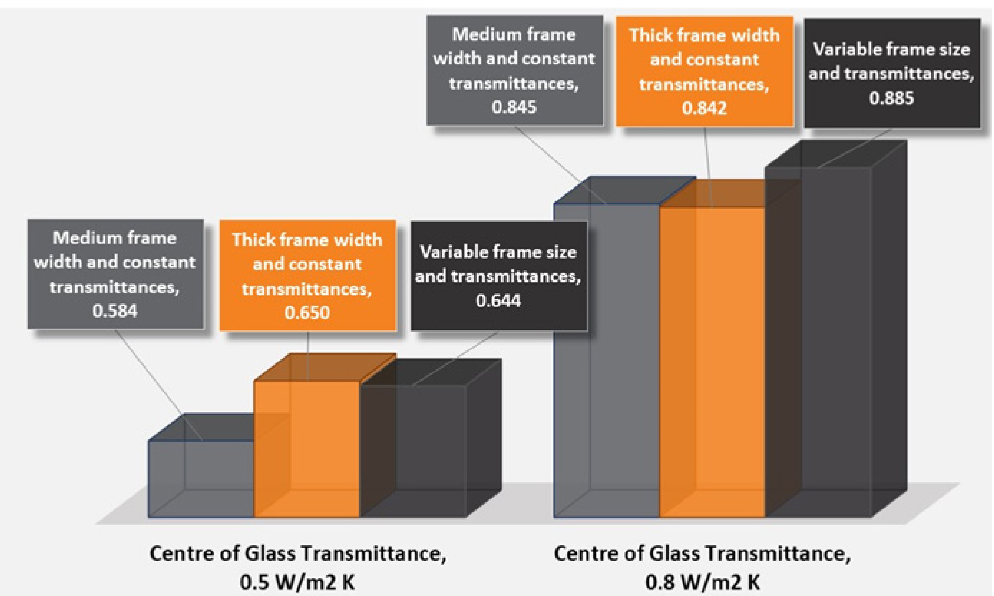
Performance-based specifications require special attention when targeting Passive House certification. Thermal data needs to be provided per Passive House (ISO) standards for certification and North American standards much be followed to meet the building code. Converting between standards is not straightforward and no standard is deemed more stringent in all aspects. This situation often leads to confusion during tendering. To avoid this confusion, performance-based specifications should clearly reference and match the relevant standard. The requirement for thermal data evaluated per ISO standards may limit North American window products as a result of not having readily available data per ISO standards. Nevertheless, there are free tools available to assist in making the conversions between standards[4].

Example Cladding Attachment Arrangement

Glazing Performance

Glazing systems should be specified by the maximum thermal transmittance (U-value). Listing transmittances for individual glazing components (such as the glass, frame, and spacer) is convenient for scaling the U-value to different window sizes, but is problematic for performance-based specifications.

The overall U-value is dependent on how the individual components are factored together as a system. For example, one type of frame might yield better results for a low center of glass transmittance but a difference frame yields better results for a higher center of glass transmittance. Specifying a maximum U-value facilitates optimization between the transparent glazing and opaque walls and provides the means to objectively evaluate various proposed solutions during tendering



Glazing System Thermal Transmittance (W/m²K) for a 2 m x 1.5 m window

Window-to-Wall + Interfaces

Specifying a performance-based target for the window-to-wall interface can be difficult because this is not common practice and numerous trades may be involved who are not familiar with linear transmittances. However, mitigation requires a multi-faceted approach and cannot be downloaded to a single design team member or trade.

Thermal bridging through window-to-wall interfaces is not a window-related problem nor a wall-related problem, but rather how the two are inter-connected. The easiest approach could be to contract the entire façade to a single trade, and not allow any variation in the design during tendering and construction. However, the lack of flexibility with this approach often precludes it from being the most cost-effective solution.

It may be tempting to prescriptively specify how to detail an interface to minimize the thermal bridging. Reasons often surface during construction as to why a specific system cannot be positioned as detailed, why the flashing cannot be installed as detailed, or why a large structural angle that was not part of the glazing shop drawings must be installed. For NZER buildings the entire team will likely not appreciate the impact of proposed changes or may not be familiar to how to maintain the thermal quality of a detail. For these reasons, it may be prudent to specify a maximum linear transmittance for each interface and require the detail to be evaluated (such as through thermal modeling) if a significant change to the detail is proposed.

> The most cost-effective solutions often are achieved when there is some flexibility for the design and construction teams and willingness to flexibility and willingness to consider alternative approaches. Carefully considering all options can contribute to a successful project outcome.

Avoiding Common Pitfalls

Mitigating thermal bridging on NZER projects should be a collaborative effort, with the design team united towards meeting the project's energy targets. While calculations should be thorough and use accurate data, if design teams become too focused on accounting for every detail or component, regardless of significance, it can paralyze decision-making. This can cause unnecessary delays without providing any actual benefit to the project. Much of this can be avoided by following the processes outlined in this playbook. Here are some further tips to help avoid other common pitfalls:

Do not model the energy performance of every project-specific detail when available generic data will suffice[3]. Small differences between project-specific assemblies and generic data (such as the difference between ½" and 5/8" thick sheathing) makes little difference.

Do not get hung up on thermal simulation details such as boundary conditions between different thermal bridging standards and conventions. Boundary conditions often makes little difference for the opaque building envelope. See the *Guide to Low Thermal Energy Demand*[1] for more information on comparing standards. Boundary conditions are heat transfer coefficients, temperatures, and relative that vary slightly by each standard.

Consider alternative detailing. Even if conventional detailing has worked in the past, it might not be good enough for NZER projects. There are no one-size-fits-all solutions. Be open to exploring new approaches and innovative solutions. This is especially true for window-to-wall interfaces.

Start with conservative values for thermal bridging. Give projects a performance buffer in early design for the assemblies and details. This will allow greater flexibility in later design development and tendering. Setting the insulation levels based on conservative assumptions for the impact of the interface details allows for the possibility of mitigating the details to improve performance without affecting the wall dimensions.

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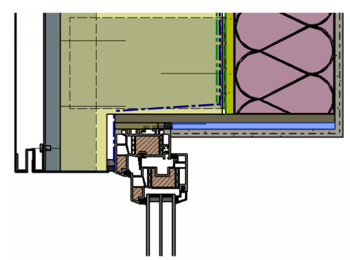
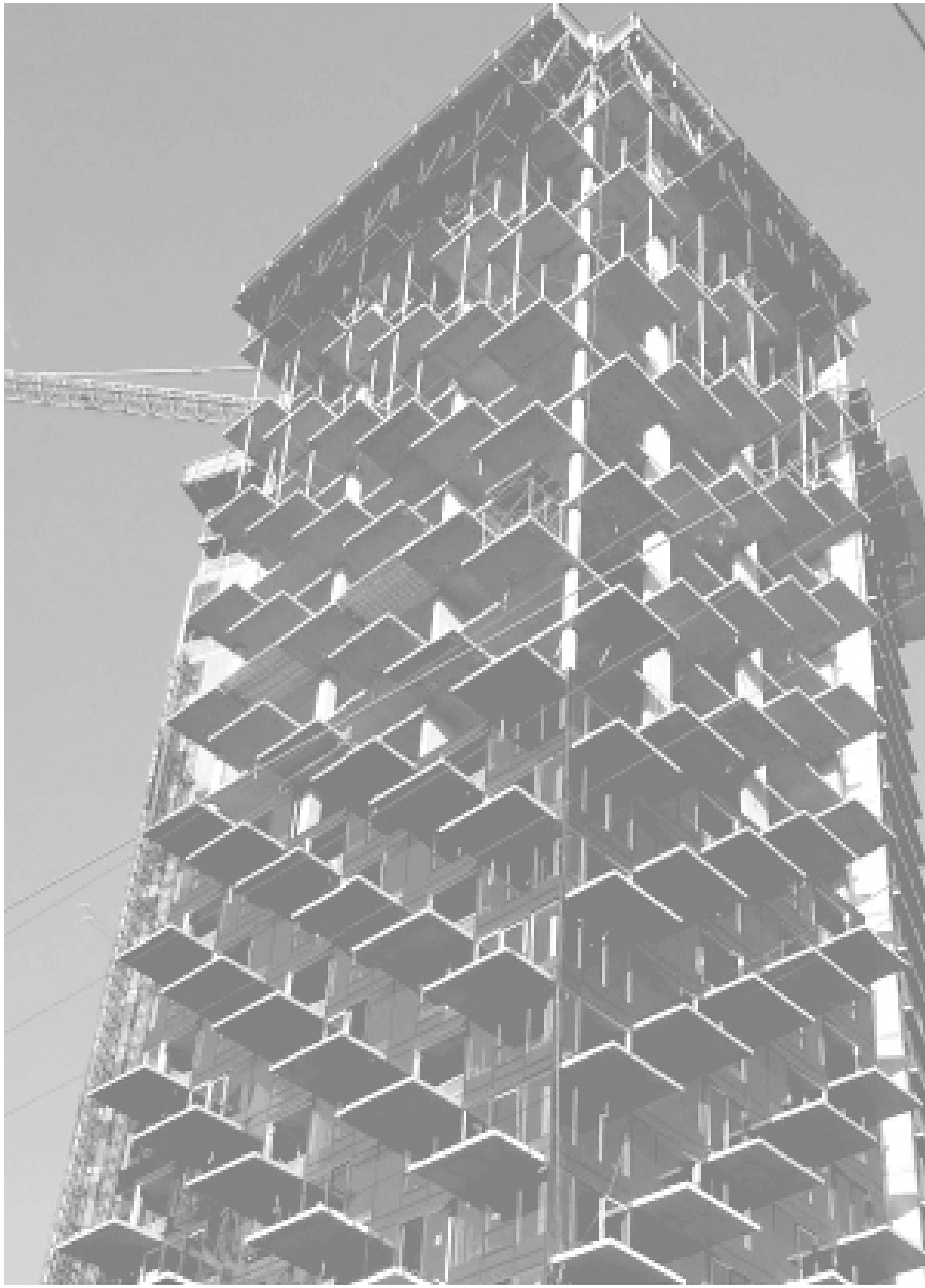


Always determine the relative heat flow contributions of each detail. Avoid the assumption that a building needs a specific product, like a balcony thermal break, while overlooking how the product is installed. The gain in performance can be significantly negated by bypassing the thermal break with flashing or not properly insulating around the perimeter of the thermal break.

Do not focus on just one component. Consider how the detail will impact the overall performance or ultimately change the design. Test the impact of the detail by using a range of estimates.

Use performance based specifications for the project requirements (loads) and factor in the type of cladding and layout. This is especially important for cladding attachments. If specifications are based on the thermal performance of a clip system on a *universal spacing* instead of the project-specific requirements, the thermal performance of the building envelope is likely to be affected. This can create headaches for final energy performance compliance and conflicts with early design decisions are often recognized too late.

Remember that energy efficiency is not everything. There are many other performance criteria that make a project successful, such as durability, occupant comfort, constructibility and costs.



Extended Concrete Balconies

Additional Resources

For more information on this topic, please see the following publications and information sources:

- Building Envelope Thermal Bridging Guide, BC Hydro
- Guide to Low Thermal Energy Demand in Large Buildings, BC Housing, 2018
- Proposed CSA Z5010 Thermal Bridging Calculation Methodology, CSA Group
- Building Pathfinder, OGBS
- www.ThermalEnvelope.ca, BC Housing
- ISO Standard 12011 Thermal Bridges in Building Construction - Heat Flows and Surface Temperatures - Detailed Calculations, International Organization for Standardization, 2017
- ISO Standard 14683 Thermal Bridges in Building Construction - Linear Thermal Transmittance - Simplified Methods and Default Values, International Organization for Standardization, 2017

End Notes

1 Source: BC Energy Step Code Design Guide
https://www.bchousing.org/publications/BC-Energy-Step-Code-Design-Guide-Supplement.pdf

2 Source: BETB Guide Part 3: Significance, Insights and Next Steps
https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/final-mh-bc-part-3-impacts.pdf

3 Source: The Building Envelope Thermal Bridging Guide version 1.5
https://www.bchousing.org/research-centre/library/residential-design-construction/building-envelope-thermal-bridging-guide or www.bchydro.com/thermalguide

4 Source: FENBC THERM PHPP Reference Procedure
https://www.fen-bc.org/resource_details.php?id_resource=3

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