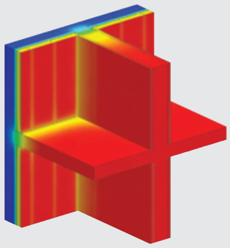

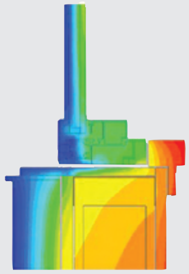

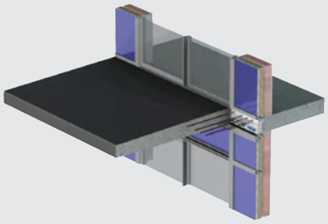

Building Envelope Thermal Bridging Guide

ANALYSIS, APPLICATIONS & INSIGHTS

BC hydro powersmart

Homeowner Protection Office
Branch of BC Housing

Canadian Wood Council
Conseil canadien du bois

FORTIS BC

FPInnovations

Morrison Hershfield

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Fortis BC
FPInnovations
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DISCLAIMER

This publication is provided to inform the practice of applying the Building Envelope Thermal Analysis (BETA) methodology for determining the effective thermal performance of building envelope assembly and interface details, as well as to guide BETA's application in overall building design. The greatest care has been taken to confirm the accuracy of the information contained herein. However, the authors, co-sponsors, industry advisors, industry partners and other contributors assume no liability for any damage, injury, loss or expense that may be incurred or suffered as result of the use of this publication, building envelope design methodology or energy modeling practices. The views expressed herein do not necessarily represent those of any individual contributor. Nothing in this publication is an endorsement of any proprietary building envelope system or particular assembly product.

In addition to using this publication, readers are encouraged to consult applicable up-to-date technical publications on building envelope science, practices and products. Retain consultants with appropriate architectural and/ or engineering qualifications and speak with appropriate municipal and other authorities with respect to issues of envelope design, assembly fabrication and construction practices. It is also advisable to seek specific information on the use of envelope-related products and consult the instructions of envelope assembly manufacturers. Always review and comply with the specific requirements of the applicable building codes for any construction project.

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INTRODUCTION

In British Columbia, a large percentage of electricity and natural gas is consumed in commercial, institutional, and residential buildings. Improved energy conservation in buildings has long been recognized as an important approach to reduce energy consumption and greenhouse gas emissions in BC. Government and utilities have a mandate to encourage energy conversation in buildings and BC jurisdictions have been adopting increasingly more stringent building energy efficiency standards. Space conditioning, primarily heating, is one of the largest components of energy use in commercial, institutional, and residential buildings in BC. Building envelope thermal performance is a critical consideration for reducing space heating loads and will be an increasingly important factor as authorities strive for lower energy consumption in buildings.

It has become more and more evident that the thermal performance of the building envelope can be greatly affected by thermal bridging. Thermal bridges are localized areas of high heat flow through walls, roofs and other insulated building envelope components. Thermal bridging is caused by highly conductive elements that penetrate the thermal insulation and/or misaligned planes of thermal insulation. These paths allow heat flow to bypass the insulating layer, and reduce the effectiveness of the insulation.

Figure 1: Thermal Bridging due to a Shelf Angle that supports Brick Veneer

Research and monitoring of buildings is increasingly showing the importance of reducing thermal bridging in new construction and mitigating the impact in existing buildings. The impact can be significant to whole building energy use, the risk of condensation on cold surfaces, and occupant comfort. The traditional approach of building codes to reducing space heating loads in buildings was to introduce progressively higher levels of thermal insulation and more stringent glazing performance requirements. This was a logical approach in the past because standard practice was to largely overlook thermally bridging. The effects of thermal bridging were assumed to be negligible if the cross-sectional areas of these conductive components were small, relative to the rest of the building envelope or they were purposely ignored due to the difficulty in assessing the impact. However, the additional heat flow due to major thermal bridges, including ones with small cross sectional areas such as shelf angles or flashing around windows, can add up to be a significant portion of the heat flow through opaque envelope assemblies. For example, the contribution of details that are typically disregarded can result in the underestimation of 20% to 70% of the total heat flow through walls. If major thermal bridges are not addressed then adding insulation to the assemblies may not provide significant benefits in reducing the overall heat flow because heat will flow through the path of least resistance. The cost of adding extra insulation, not just additional materials but also potentially reduced useable floor space, is not justified if no substantial energy savings are realized in practice.

Energy standards and codes in BC jurisdictions (BCBC, VBBL, ASHRAE 90.1and NECB) do not currently effectively address, or explicitly allow designers to ignore, major thermal bridges such as slab edges, shelf angles, parapets, window perimeters, etc. These codes and standards have steadily increased their insulation requirements but the development and implementation of procedures to effectively address thermal bridging in these codes has been slow. Some reasons for the slow response include: absence of data, the complexity of some prevailing procedures to account for thermal bridging, and a lack of clear information demonstrating that thermal bridging needs to be more thoroughly addressed. Moreover, reaching agreement for how to implement significant changes to codes and standards can be challenging for committees comprised of a wide range of interests, backgrounds and perspectives.

With this context in mind, this guide explores how the building industry in BC can realistically meet the challenges of reducing energy use in buildings, in part by effectively accounting for the impact of thermal bridging. The goal of the co-sponsors of this guide is to help transform the BC construction sector to realize more energy efficient buildings. To help meet this goal, the primary objective of this guide is to address the obstacles currently confronting our industry, with regard to thermal bridging, by:

1. Providing a catalogue of the thermal performance of common envelope assemblies and interface details directly relevant to construction in BC.
2. Providing information that makes it easier for industry to comprehensively consider thermal bridging in building codes and bylaws, design, and whole building energy simulations.
3. Examining the costs associated with improving the thermal performance of opaque building envelope assemblies and interface details, and forecasting the energy impact for several building types and BC climates.
4. Evaluating the cost effectiveness of improving the building envelope through more thermally efficient assemblies, interface details, and increasing insulation levels.

Scope

It is important to recognize that this guide is deliberately narrow in scope. The focus is on the thermal performance of the opaque building envelope. A wide range of opaque assemblies were evaluated in preparation of this guide; however, the thermal performance of the opaque building envelope is only one of many considerations for reducing energy use in buildings and its relative impact changes as other building energy uses are reduced. The building archetypes selected for the whole building energy analysis in this guide were chosen to cover the typical energy end use distributions in the current BC building market, with performance characteristics based on current market practice.

Audience

The target audiences for this guide are broad: committees for energy standards, policy and government, utilities, architects, mechanical designers, building envelope consultants, energy modellers, developers and contractors, manufacturers and trade organizations. Not all the information contained in the guide will be of direct interest to all these industry stakeholders. To provide easy access to information, the guide is broken up into three stand-alone main sections:

- **Part 1:** Building Envelope Thermal Analysis (BETA) Guide
- **Part 2**: Energy Savings and Cost Benefit Analysis
- **Part 3**: Significance, Insights and Next Steps

Each section begins with an overview, highlighting important information for the various target audiences, a summary of analysis completed in preparation of each section and a discussion of how to use the information in practice.

GLOSSARY OF TERMS

Term	Symbol	Units Imperial	Units SI	Description
Conductivity	K	$\frac{(BTU\ in)}{(hr\ ft^2\ {}^oF)}$	$\frac{W}{(m^oK)}$	The ability of a material to transmit heat in terms of energy per unit area per unit thickness for each degree of temperature difference.
Equivalent Conductivity	K_{eq}	$\frac{(BTU\ in)}{(hr\ ft^2\ {}^oF)}$	$\frac{W}{(m^oK)}$	The averaged or equivalent thermal conductivity of a component consisting of several building materials, effectively treating the component as a homogeneous material that provides the same thermal characteristics.
Heat Flow	Q	BTU/hr	W	The amount of energy per unit time that passes through an assembly under a specific temperature drive of ΔT.
Thermal Transmission Coefficient	U	$\frac{(BTU)}{(hr\ ft^2\ {}^oF)}$	$\frac{W}{(m^2\ {}^oK)}$	Heat flow per unit time through a unit area of an assembly per temperature degree difference. The convention is to include the impact of air films
Thermal Resistance of a Material	R	$\frac{(hr\ ft^2\ {}^oF)}{(BTU)}$	$\frac{(m^2\ {}^oK)}{W}$	A measure of a material's resistance to heat flow.
Effective Thermal Resistance	R_{eff}	$\frac{(hr\ ft^2\ {}^oF)}{(BTU)}$	$\frac{(m^2\ {}^oK)}{W}$	A measure of an assembly's resistance to heat flow, including the effects of thermal bridging. The inverse of the assembly U-value.
Clear field Assembly Thermal Transmittance	U_0	$\frac{(BTU)}{(hr\ ft^2\ {}^oF)}$	$\frac{W}{(m^2\ {}^oK)}$	Heat flow coefficient for an assembly with uniformly distributed thermal bridges, which are not practical to account for on an individual basis for U-value calculations. Examples of thermal bridging included in U_o are brick ties, girts supporting cladding, and structural studs.
Linear Heat Transmittance Coefficient	Ψ	$\frac{(BTU)}{(hr\ ft\ {}^oF)}$	$\frac{W}{(m\ {}^oK)}$	Heat flow coefficient representing the added heat flow associated with linear thermal bridges that are not included in the clear field U_o. Linear thermal bridges typically occur at interface details. Examples are shelf angles, slab edges, balconies, corner framing, parapets, and window interfaces.
Point Heat Transmittance Coefficient	χ	$\frac{(BTU)}{(hr\ {}^oF)}$	$\frac{W}{({}^oK)}$	Heat flow coefficient representing the added heat flow associated with a point thermal bridge that is not included in the clear field U_o. Point thermal bridges are countable points and are considered feasible to account for on an individual basis for U-value calculations. An example is a structural beam penetration through insulation.
Length of a Linear Transmittance	L	ft	m	The length of a linear thermal bridge, i.e. height of a corner or width of a slab.

Term	Description
Air Films	An approximation of the combined radiative and conductive-convective heat exchange at air boundary surfaces.
Area of Influence	The area that heat flow through an assembly is affected by a thermal bridge by lateral heat flows.
Area Weighted Method	The method by which an average U-value is determined by summing the Area multiplied by U-Value of each component and then dividing by total Area. This method assumes parallel heat flow paths.
At-Grade Interface Detail	An interface detail at the transition between the above-grade wall assembly intersections with either an at-grade floor slab or below grade assemblies.
Building Elevation	A view of a building seen from one side, a flat representation of one façade. Elevations drawings typically show views of the exterior of a building by orientation (North, East, South or West).
Building Envelope	The elements of a building that separate the conditioned space from unconditioned space of a building. This includes walls, roofs, windows and doors.
Clear Field Assembly	Wall, floor and roof assemblies of a building. (see definition of U_0 above).
Corner Interface Detail	Where walls meet at a corner of the building. Interface details can have additional heat flow than compared to the clear field assembly because of additional framing and related to the geometry (increased exterior surface area).
Curtain Wall	A non-load bearing building façade that sits outboard of the main building structure made up of metal framing, vision glass and spandrel sections. The curtain wall only carries its own dead-load and lateral loads (wind).
Dynamic Thermal Response	The time variant heat flows through the building envelope that result in delayed heat gain or loss depending on the amount of energy that is stored within the building envelope. The amount of energy that is stored within the building envelope at any given time is related to the mass of all the combined components of the building envelope (thermal mass).
Eyebrow	An architectural feature where the floor slab projects beyond the walls. Eyebrows often provide overhead protection from rain for fenestration and are similar in construction to a balcony.
Fenestration	All areas (including the frames) in the building envelope that let in light, including windows, plastic panels, clerestories, skylights, doors that are more than one-half glass, and glass block walls.
Firestop	A fire protection system made of various components used to seal openings and joints in fire-resistance rated wall and floor assemblies.
Floor Space Ratio	Ratio of gross floor area of a building to the area of land on which it is built.
Glazing	See definition of fenestration. Examples of glazing are windows, window-wall, and curtain-wall.
Glazing Interface Detail	Linear thermal bridges that occur at the intersection of glazing and opaque assemblies.

Term	Description
Insulating Glass Unit (IGU)	Double or triple glass planes separated by air or other gas filled space. The space between the panes is glass is created by a physical spacer that is also adhered to the glass. Sealant is provided at the perimeter of the unit as a gas and moisture barrier.
Interface Details	Thermal bridging related to the details at the intersection of building envelope assemblies and/or structural components. Interface details interrupt the uniformity of a clear field assembly and the additional heat loss associated with interface details is accounted for by linear and point thermal transmittances.
Lateral Heat Flow	Heat flow in multiple directions through an assembly as a result of conductive components bypassing the thermal insulation in multiple dimensions.
Linear Thermal Bridge	An interface detail that can be defined by a linear length along a plane of the building envelope.
MURB	Multi-unit residential building.
Opaque Assembly	All areas in the building envelope, except fenestration and building services openings such as vents and grilles.
Parallel Path	The assumption that the heat flow paths through an assembly are perpendicular to the plane of the assembly and there is no lateral heat flow.
Parapet	An interface detail that joins the walls to the roof.
Point Thermal Bridge	Points of heat loss that are considered feasible to account for on an individual basis for U-value calculations. An example is a structural beam penetrations through insulation.
Poured-in-Place Concrete Wall	An architectural exposed concrete wall that is formed at the location of installation and is part of the building structural support.
Precast Concrete Wall	An architectural concrete cladding that is formed off site and shipped to the location of installation.
Plane of Heat Transfer	The theoretical projected area between the interior and exterior environment where the net heat flow through the building envelope is calculated.
Plug Loads	Any system that draws electrical power through the building, but is not explicitly used to operate the building. This includes appliances, computers and other items that are dependent on the occupants use.
Setpoint Temperature	The desired operating temperature that a heating system works to maintain, ie: the interior space temperature set by a thermostat.
Shelf Angle	A structural support that transfers the dead load of brick veneer to the building structure at the floor slab.
Floor Slab	A concrete floor that partially or fully penetrates the building envelope at the exterior.
Slab Bypass	A portion of window-wall that covers the floor slab edge to give the appearance of uninterrupted glazing across the entire façade of a building.
Spandrel Section	An opaque section of curtain wall or window wall with insulation between the system framing.

Term	**Description**
Stick Built Curtain Wall	A site installed and glazed curtain-wall system that is assembled by running long pieces of framing between floors vertically and between vertical members horizontally.
Structural Beam	A steel beam that penetrates through the building envelope to support an exterior element, such as a canopy.
Quantity Takeoff	A quantity measurement that determines the areas and lengths needed for U-value calculations. The quantities are determined using architectural drawings.
Thermal Break	A non-conductive material that interrupts a conductive heat flow path. For example, aluminum framing for glazing in cold climates typically utilizes a low conductivity material to join an exterior and interior portion of the metal framing.
Thermal Bridge	Part of the building envelope where otherwise uniform thermal resistance is changed by full or partial penetration of the thermal insulation by materials with lower thermal conductivities and/or when the interior and exterior areas of the envelope are different, such as what occurs at parapets and corners.
Thermal Modeling	The process by which the thermal performance of assemblies is determined through computer simulations utilizing heat transfer models. Assemblies can be modeled two- or three- dimensions (2D and 3D).
Thermal Performance	A broad term to describe performance indicators related to the heat transfer through an assembly. The performance indicators include thermal transmittances, effective R-values, and metrics to evaluate condensation resistance related to surface temperatures.
Thermal Zone	A grouping of the interior building spaces that experience similar heating and cooling requirements.
Total Energy Use	The amount of annual energy use of a building, including space heating/cooling, ventilation, lighting, plug loads, domestic hot water, pumps, fans etc.
Unitized Curtain Wall	A curtain-wall system that is assembled in modules that is glazed before arriving at site.
Vision Section	The section of curtain-wall or window-wall that contains transparent or translucent elements.
Window to Wall Ratio/ Glazing Ratio	The percentage of glazing to the wall area of a building.
Window-wall	A factory built modular façade system installed from floor to ceiling that is supported by the floor slab. This could include a vision and a spandrel section.
Whole Building Energy Use	The amount of energy a building uses, typically on a yearly basis. This includes, but is not limited to energy for space and ventilation heating and cooling, domestic hot water heating, lighting, miscellaneous electrical loads and auxiliary HVAC equipment such as pumps and fans.

PART 1
BUILDING ENVELOPE THERMAL ANALYSIS (BETA) GUIDE

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1.1 OVERVIEW

The evaluation of energy use in buildings requires a reasonably accurate assessment of heat transfer through the building envelope which includes the heat passing through thermal bridges at interfaces and penetrations. A previous study, ASHRAE 1365-RP "Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings" (Morrison Hershfield Ltd, 2011), put forward procedures and data that allowed practitioners to evaluate the impact of thermal bridging in a comprehensive and straightforward method. This has started a market transformation to better evaluate building performance and design for energy conservation. 1365-RP, which contained 40 common building envelope assemblies for mid- and high-rise construction, was a good start in creating a building envelope thermal performance catalogue. However, that report only scratched the surface, particularly in identifying how to effectively mitigate thermal bridging in design. Part of the intent of this guide is to expand on the previous work, including showing where opportunities exist to incentivize improving industry practice.

In preparation for this guide, the analysis of the thermal performance of typical building assemblies was expanded upon, including evaluation of many more assembly details that are in common use in the BC building industry. Also, emerging technologies and construction practices were explored that offer substantial improvements to current construction practice.

This section of the report, the Building Envelope Thermal Analysis (BETA) guide, focuses on summarizing the impact of thermal bridging on the thermal performance of building envelope assemblies and how to utilize this information in practice.

From a high level awareness perspective, the information provided in this section is relevant to all the target audiences. All stakeholders should be aware of the information, understand the benefits of the methodology, and understand in concept how the methodology and data can be used in practice. Only designers, architects, engineers, energy modelers, and building envelope consultants really need to delve deep into the methodology and fully understand how to utilize the thermal performance data in practice.

1.2 METHODOLOGY FOR DETERMINING THERMAL PERFORMANCE OF BUILDING ENVELOPE ASSEMBLIES

1.2.1 METHODOLOGY SUMMARY

The performance data prepared for this guide was determined by following the same methodology as 1365-RP and using the same 3D thermal modeling package that was extensively calibrated and validated as part of that work. Detailed information on the background of the methodology can be found in the final report for 1365-RP. What follows is an outline of the important points of that methodology.

In determining the thermal performance of the building envelope that includes thermal bridging, a basic distinction must be made between two types of opaque building components, clear field assemblies and interface details, examples of which are shown in Figures 1.1 and 1.2 respectively.

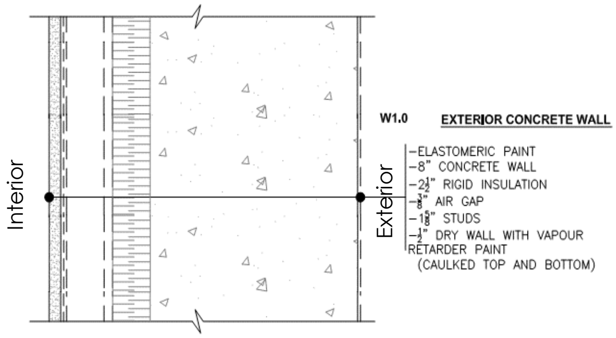


Figure 1.1: An example of a clear field assembly drawing

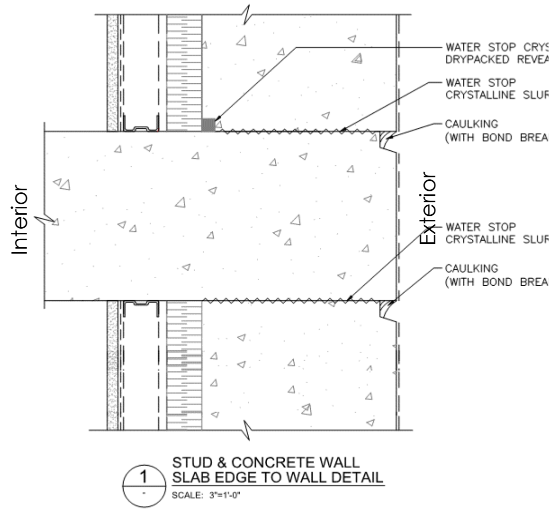


Figure 1.2: An example of an envelope interface detail drawing

Clear field assemblies are wall, roof or floor assemblies that include all the components that make up a wall, including structural framing. These are typically found in the architectural drawings in the wall/roof/floor schedules. Clear field assemblies can contain thermal bridges from uniformly distributed secondary structural components which are needed for the wall to resist loads, but do not include thermal bridges related to intersections to the primary structure or between assemblies. Examples of components included in clear field assemblies are brick ties, girts that support cladding and/or studs.

Interface details are changes in construction or geometry that interrupt the uniformity of the clear field. These are typically found in the detail sections in architectural drawings. These include slab edges, opaque to glazing or wall transitions, parapets, corners and through wall penetrations.

Determining the impact of heat flows through the clear field and through interface details is necessary to accurately assess the thermal transmittance of building envelope assemblies.

A Note on Glazing

Glazing in buildings can have an incredibly large influence on building energy use, especially in designs that have high window to wall ratios. Glazing portions of the building envelope are often dealt with separately from the opaque elements because of the additional effects of solar heat gain. Thermal analysis and testing of glazing systems in North America typically follow standards by the National Fenestration Rating Council (Mitchell, et al., Rev 2013). Following this guide to determine the thermal performance of opaque elements and NFRC standards for glazing is compatible. While the thermal performance of glazing assemblies can affect the thermal resistance of adjacent wall or roof assemblies, the heat loss is accounted for through the **window to wall transition** thermal values described later in this guide.

1.2.2 DETERMINING THERMAL PERFORMANCE OF CLEAR FIELD ASSEMBLIES

The thermal performance of clear field assemblies can be determined through calculation, modeling or physical testing. Typically this takes the form of a U-value or effective R-value.

- The **ASHRAE Handbook of Fundamentals** (ASHRAE, 2013) provides several methods to determine clear field U-values using hand calculations. These hand calculations are meant for simple assemblies with only thermal bridges in one or two dimensions. These methods are described in more detail in the Handbook of Fundamentals.
- For assemblies where the 2D heat flow paths can influence each other and are more complex than appropriate for hand calculations, then 2D thermal modeling can be utilized to approximate the thermal performance of building envelope details. Software for this type of modeling (such as **THERM**, (Mitchell, et al., Rev 2013) is widely available and used in industry for two-dimensional thermal modeling. Approximations need to be made for components that are not continuous or occur in three dimensions, such as creating an equivalent thermal conductivity. These approximations can be sufficient in many cases for determining the expected thermal transmittance of opaque assemblies, but cannot be used to determine surface temperatures.
- For complex geometries and configurations where 2D heat flow assumptions are no longer valid, then 3D modeling or physical testing is often necessary for more accurate approximations of thermal performance. As stated previously, the clear field and detail values prepared for this guide were determined through 3D modeling.

It is typically only necessary to model or test a clear wall assembly if it is a new or unique design when information is not available. The construction industry has a wide variety of resources accessible to designers which contain thermal performance values for many types of clear field assemblies. Clear field assemblies analyzed for this guide are discussed in section 1.3.1 with additional information and thermal performance values provided in Appendices A and B. Other sources of information beyond this guide are discussed further in section 1.3.3.

1.2.3 DETERMINING THERMAL PERFORMANCE OF INTERFACE DETAILS – AREA WEIGHTED APPROACH

Area weighted calculations are commonly used to calculate U-values or effective R-values of the combined effect of assemblies and interface details. Typically, this is done by weighting the heat flow through the materials by the area they take up. While this can be applied easily to simple clear field assemblies, the question that arises when applied to interface details is **what is the area of a thermal bridge?**

Using only the physical area of a thermal bridge assumes that the heat flow paths through an interface detail are one-dimensional and parallel. Unfortunately, this is rarely true, and highly conductive building components create lateral heat flows to other components in three dimensions that are not accounted for in basic parallel flow assumptions. A steel shelf angle holding up a brick wall may seem small from the outside, but it is connected to many other components behind the brick and heat can easily flow around the insulation.

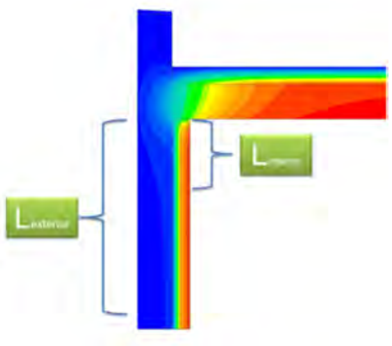


Figure 1.3: Areas of influence of a parapet detail differ from the interior and exterior of the wall

To improve simple parallel path assumptions, an area of influence of a thermal bridge has been utilized in the past. This requires finding out the distance where the heat flow through the assembly is no longer affected by the thermal bridge. The heat flow through this area is then used as a combined U-value for the wall and the thermal bridge. However, determining areas of influence of many common thermal bridges is incredibly difficult. Lateral heat flows caused by conductive elements allow heat to be transferred in multiple directions for large distances. This can create large differences in areas of influence depending on whether you are looking from inside or outside.

Using the area weighted approach can produce reasonable results when analyzing structures with low thermal conductive structural members, such as some wood-frame configurations. However, this approach can be complicated and difficult to use in practice for detailed analysis of the heat transfer through building envelopes constructed with moderate to highly conductive materials like concrete, steel and aluminum.

1.2.4 Determining Thermal Performance of Interface Details Utilizing Linear Transmittances

Linear and point transmittances can simplify things by ignoring the area of thermal bridges altogether. With this approach, the heat flow through the interface detail assembly is compared with and without the thermal bridge, and the difference in heat flow is related to the detail as heat flow per a linear length or as a point heat flow.

To illustrate how this works, let's apply this method to an exterior insulated steel stud wall with a cantilevered balcony slab that is a direct extension of the concrete structural floor slab, as shown in Figure 1.4:

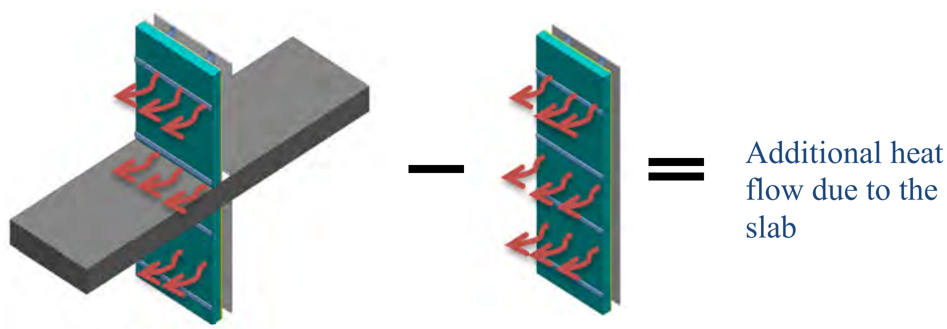


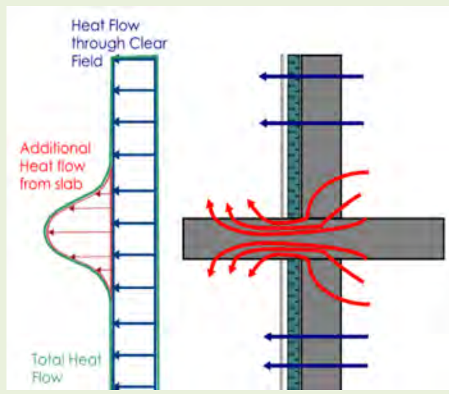
Figure 1.4: Determining linear transmittance for a slab

First, the heat flow through the interface detail assembly with the slab is determined. Next, the heat flow is determined through the assembly as if the slab was not there (you may recognize this as the clear field assembly). Since the clear field does not contain the slab, which is a large thermal bridge, the amount of heat flow is less. The difference in overall heat flow between the two assemblies is the extra amount caused by the balcony/floor slab bypassing the thermal insulation. Dividing by the assembly width (linear length of the slab edge) creates the linear transmittance of the slab, which is a heat flow per linear length.

With linear transmittances, the extra heat flow prescribed to the floor slab is not dependent on the area of the thermal bridge, but only by the linear length (width) of the balcony slab. A point transmittance is similar in concept, but is a single point of additional heat flow, not dependent on area or length. Since the linear and point transmittances are separate from the clear field, they can be directly compared to assist in determining the most appropriate details for a building. Calculated linear and point transmittances along with the clear field transmittance can be used to determine the overall heat flow for any size of wall or roof that use those components.

As with the clear field assemblies, there are additional information sources that have thermal performance values for common linear and point transmittances, albeit they are not as widely available. The performance catalogue in this guide, discussed in section 1.3, consolidates several of the linear and point transmittance as determined using the method set forth in 1365-RP. However, there are other sources available which are detailed further in section 1.3.3.

Superimposing Heat Flows



Another way of looking at the basic concept of linear transmittance is by superimposing the heat flows from the full assembly, with an interface detail, and the clear field assembly, without the interface detail, over top of each other.

From this figure you can visualize the lateral heat flows to the path of least resistance through the interface detail assembly (i.e. through the slab). This results in a higher heat flow at the slab compared to if it was only the clear field. Far away enough from the slab and the heat flow reaches the same level as in the clear field. By subtracting the clear field from the total interface detail assembly leaves the additional heat flow from just the slab, from which we get the linear transmittance.

1.2.5 DETERMINING OVERALL THERMAL PERFORMANCE

The thermal performance values of each of the envelope components can be used to calculate an overall thermal transmittance (U-value) for building envelope assemblies that include thermal bridging. Summarizing the approach so far, the thermal transmittances used in the calculations comprise of three separate categories:

- **Clear field transmittance** is the heat flow from the wall, floor or roof assembly. This transmittance includes the effects of uniformly distributed thermal bridging components, like brick ties, structural framing like studs, and structural cladding attachments that would not be practical to account for on an individual basis. The clear field transmittance is a heat flow per area, and is represented by a U-value denoted as the clear field **(U_o)**.

- **Linear transmittance** is the additional heat flow caused by details that are linear. This includes slab edges, corners, parapets, and transitions between assemblies. The linear transmittance is a heat flow per length, and is represented by psi **(Ψ)**.

- **Point transmittance** is the heat flow caused by thermal bridges that occur only at single, infrequent locations. This includes building components such as structural beam penetrations and intersections between linear details. The point transmittance is a single additive amount of heat, represented by chi **(χ)**.

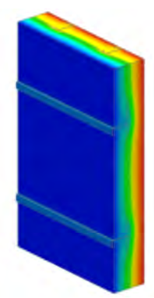


Figure 1.5: Example clear field assembly

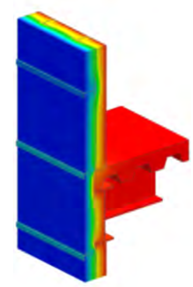


Figure 1.6: Example linear transmittance of a floor slab detail

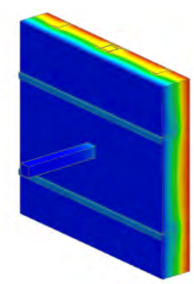


Figure 1.7: Example point transmittance of a beam penetration detail

The overall U-value for any building envelope section is a simple addition and multiplication process. In straightforward terms this amounts to:

$$\begin{matrix}\text{Total Heat flow per area} \\ \text{through the overall assembly}\end{matrix} = \frac{\begin{matrix}\text{Heat flow through} \\ \text{linear transmittances}\end{matrix} + \begin{matrix}\text{Heat flow through} \\ \text{point transmittances}\end{matrix}}{\text{Total Area of assembly}} + \begin{matrix}\text{Heat flow per area through} \\ \text{clear field assembly}\end{matrix}$$

Or, in mathematical terms:

$$U_T = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi)}{A_{Total}} + U_o$$

Where:

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

There are multiple types and quantities of linear and point transmittances, but they are all added to the clear field heat flow to get the overall heat flow of an area of the building envelope. The length for the linear transmittance depends on the detail. For example, the length used in the calculation for a floor slab bypassing the thermal insulation could be the width of the building perimeter, if this slab detail occurs around the whole façade of the building. Alternatively, a corner detail length could be the height of the building envelope.

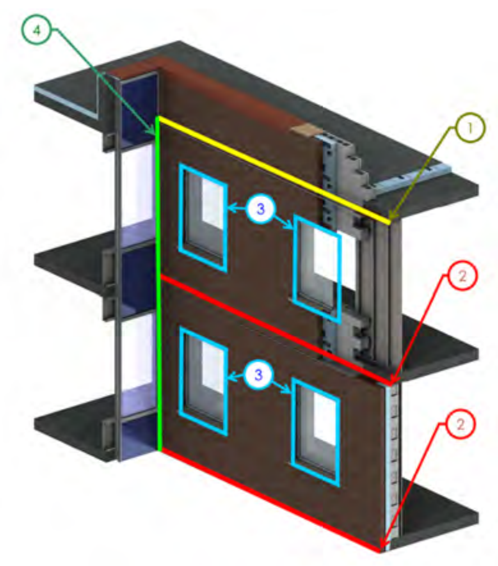
By finding the heat flows separately, each component can be evaluated to find their relative contribution to the overall heat flow.

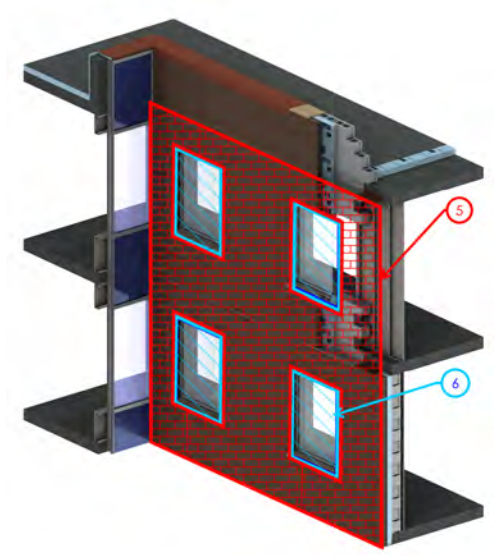
The overall U-value for a building section can be found as long as the thermal performance values for the clear field, linear and point transmittances are known along with the quantities determined by architectural drawings. These transmittances can be calculated using the procedures put forth in 1365-RP; however, modeling every detail on a project would be impractical. As such, this guide provides an extensive catalogue of assemblies where the thermal performance values have already been calculated for designers. This catalogue is discussed in more detail in section 1.3.

1.2.6 Finding Length and Area Takeoffs

Determining the overall U-value of a building section using length and area takeoffs can be fairly straight forward i.e. slab lengths along the face of a building, or corner heights; however, there are some nuances when it comes to certain interface details. The following example shows the lengths and areas for a simple brick wall section.

Example: The overall opaque wall U-value is required for the brick wall section of a building that is adjacent to a curtain-wall system. From the analysis, the designer has determined that the brick wall section contains a parapet, slab, wall to window transition and corner detail. The designer finds the thermal performance values for the brick clear wall assembly and the linear transmittances for the interface details in a thermal performance catalogue. The length and area takeoffs are shown in Figure 1.8.





1. Parapet Length
2. Slab Lengths
3. Wall to Window Transition Lengths
4. Corner Length
5. Opaque Brick Wall Area
6. Glazing Area

Figure 1.8: Example building length and area takeoffs

The glazing area above shows the differences between the glazing and opaque wall areas; however, glazing is not included with the opaque wall U-value calculations.

Once the thermal performance values of the clear wall and interface details are known, and the lengths and areas found, the overall U-value for the brick wall can be determined:

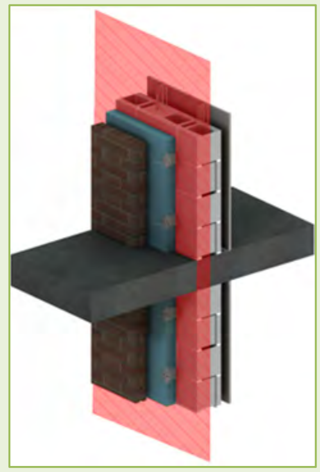
$$U_{overall} = \frac{\Psi_{parapet} \cdot L_{parapet} + \Psi_{slab} \cdot L_{slab} + \Psi_{transition} \cdot L_{transition} + \Psi_{corner} \cdot L_{corner}}{A_{Opaque\ Brick\ Wall\ Area}} + U_{brick\ clear\ wall}$$

For some of the interface details, there are additional considerations as to where to assign the extra heat flow. In the above example, the brick wall was connected to a curtain-wall system with spandrel. The corner interface detail is connected to both assemblies, and in the above calculation, the heat flow through the corner was assigned entirely to the brick wall. Alternatively, it could have been assigned entirely to the brick wall or the curtain-wall or split evenly between the two. It is up to the designer to decide how they wish to divide up the building U-values. This matters mostly for energy models as the heat flow through each envelope section gets assigned to a particular building thermal zone. This same concept applies to a parapet as it acts as a corner between the roof and the walls. However, it may not matter if the heat flow through the parapet is assigned to the wall or to the roof as both are connected to the same interior thermal zone. For wall to glazing transitions, the additional heat flow is assigned to the wall and not the glazing, thereby NFRC standards can be utilized for determining the U-value of glazing separately (Mitchell, et al., Rev 2013). When there are slabs, the clear wall area includes the projected area of slab edges, including balcony slabs.

Length and Area Takeoffs and the Plane of Heat Transfer

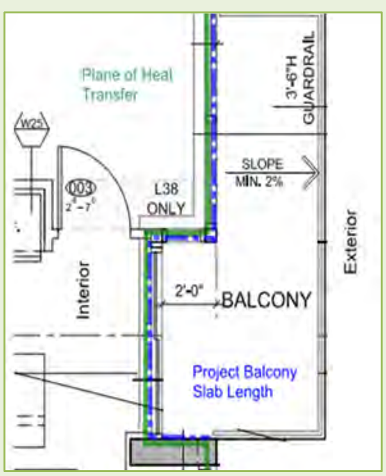
The plane of heat transfer for the building envelope is a theoretical projected area between the interior and exterior conditions through which heat flows. In order for there to be a heat loss or heat gain through the building envelope, energy must pass through this plane of heat transfer. A building assembly may have some elaborate features that extend out past the building envelope; however, all that is important for thermal performance is where the heat flow passes the plane of heat transfer into or out of the building.

Plane of heat transfer through a wall

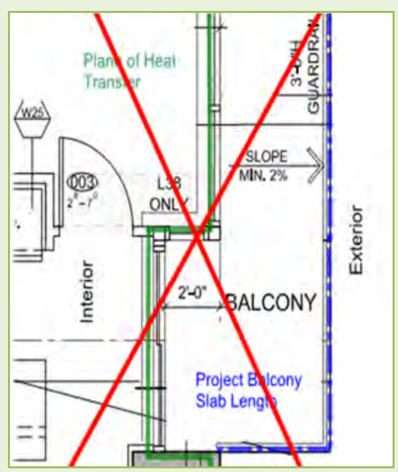


Plane of heat transfer through a projected balcony

For flat objects (i.e. walls) the plane of heat transfer is easy to visualize. With projections, such as balcony slabs, it may not be immediately intuitive where the plane is; however, since it is only important where the heat flows through the building envelope, the plane of heat transfer is the same as the flat wall. The areas of details that project out of the building envelope are not necessary for calculations. The heat flows as a result of these projections are accounted for in the linear transmittance of that detail. If there was a significant difference in heat flow as a result of the distance of the projection (i.e. a balcony that projected 1m from the wall compared to one that projects 3m from the wall) then there would be a different linear transmittance value. However, it should be noted that for the details in this guide, the projected distances of the balconies had minimal effect on the linear transmittance values for the projected slabs. When determining length takeoffs for projections for use in overall thermal performance calculations, only the lengths along the plane of heat transfer should be used. For example, for balcony slabs, use the length where the balcony intersects the wall and NOT the outside perimeter length of the balcony. Similarly for parapets, the length around the parapet is not needed.

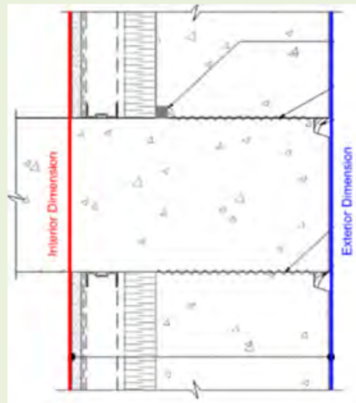


Correct Projected Balcony Slab Length for Calculations

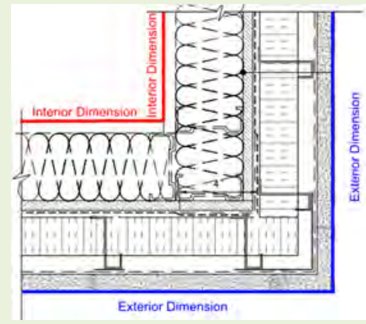


Incorrect Project Balcony Slab Length for Calculations

A Note on Length and Area Takeoffs for the Detail Oriented



Interior/Exterior Dimensions for a single plane assembly



Interior/Exterior Dimensions for a multi-plane assembly

The lengths for linear transmittances are usually easiest to find using building elevation drawings, which are exterior dimensions. Some further investigation for take offs may be required, such as looking at interior section views, when a detail is obstructed by other building features (i.e. the cladding). However, getting the takeoff lengths and areas from the exterior or the interior dimensions will result in slight differences on the overall U-value, depending on how the linear transmittances are reported. The way in which the linear transmittances are reported for this guide are such that if mixed interior and exterior dimensions are used, then the U-values will be slightly more conservative. This is typically not a concern as the differences from mixing interior and exterior dimensions are minor and there are already inherent discrepancies between architectural drawings and what is built on site. The following information is for those designers who want that extra level of precision.

The formulation of linear transmittance values is dependent on the area of the plane of heat transfer through the modeled assembly. In most cases, figuring out the plane of heat transfer is straight forward. For straight building objects, like a wall, heat transfer between the interior and the exterior is in a single plane, through the wall, so the interior and exterior dimensions will be the same. However, for an angled detail like an outside corner, the heat transfer is in more than one plane and the interior and exterior dimensions are different.

Remembering that the linear transmittance is an extra heat flow caused by an interference detail compared to the clear field heat flow, the calculation of Ψ is dependent on the area of the clear field used in the calculation. Due to conservation of energy, the heat flow in equals the heat flow out, and the overall amount is the same regardless of the dimension chosen. However, assigning the degree of that heat flow between the clear field and the detail is where the issue lies.

Example: *For the outside corner shown above, if the clear field area is assumed to be the interior dimensions, which are smaller, then the heat flow contribution from the clear field will be smaller and the rest is assigned to the corner. If the clear field is assumed to be the exterior dimensions, then the heat flow contribution through the clear field will be larger, with a smaller amount assigned to the corner. This results in a smaller or larger calculated linear transmittance depending on the dimension used, however, the resultant heat flow* ***should be identical*** *when the correct lengths are used in U-value calculations.*

If a linear transmittance for a multi-plane assembly was determined using interior dimensions, and the takeoff lengths for the detail use exterior dimensions, then the heat flow through that detail will be slightly overestimated for outside corners and parapets since the exterior dimensions are typically larger than the interior dimensions. This overestimation is the same magnitude as using exterior dimensions for any U-value calculation and is equal to the clear field U-value multiplied by the difference in area between the interior and exterior dimensions.

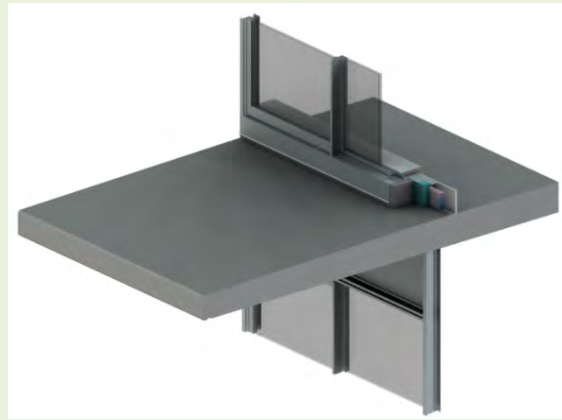
To be most precise, the locations for the takeoffs in multi-plane assemblies should match with how the linear transmittance is reported. Alternatively, the difference between the interior and exterior dimensions on either side of the corner is actually just the wall thickness. The heat flow through a section of clear wall the size of the wall thickness could be subtracted from the overall heat flow in order to remove the overestimation. However, it should be noted that multi-plane assemblies are typically parapets and corners and this may only be a consideration in smaller buildings (less than four storeys) if the parapet or corner details have a high linear transmittance.

ISO 14683 (CEN, 2007) reports multiple linear transmittances for interface details based on different dimensioning systems. While this is thorough, the intent of the methodology in ASHRAE 1365-RP (Morrison Hershfield Ltd, 2011) was to simplify calculations; therefore only one transmittance value, reported from interior dimensions, is given per insulation level per interface detail in this guide. Differences in exterior and interior dimensions with linear transmittances are further discussed in (Janssens, et al., 2007).

Dealing with Floor to Ceiling Glazing

An issue that arises when determining lengths and areas for heat loss calculations is glazing that spans floor to ceiling. In the methodology presented in the guide, glazing and opaque envelope areas are accounted for separately when calculating heat loss, with additional heat loss from interface details added to the opaque areas. Thus, a situation arises when there is floor to ceiling glazing from slab to slab and there is no discernible opaque clear wall area.

In calculating the linear transmittance of a detail, the value is based on an additive amount of heat flow from the detail to the clear field assembly associated with that detail. For example, the linear transmittance of a balcony going through an interior insulated concrete wall is the difference in heat loss between the same sized assembly with and without the balcony there. In the calculations for the overall U-value, we prescribe an area to the total assembly, and a portion of that assembly is interrupted by details. We calculate the total U-value by adding the heat loss associated with thermal bridging at interface details to the clear field heat loss. However, with floor to ceiling glazing, the slab is flanked by glazing assemblies, which presents a situation where there is not an obvious clear wall thermal transmittance.



Assembly without an opaque clear field

The linear transmittances for the details in section 8.0 Balcones and Doors in Appendix A and B were calculated by subtracting out the glazing heat flow above and below the slab. There are many possible wall assemblies that can be adjacent to the balcony sliding door and balcony slab.

Using the linear transmittance values directly and including the areas of the slabs between the floor to ceiling glazing as clear field area may result in a more conservative overall U-value since the clear field area is being over accounted for. The results for the balcony details presented in Appendix B are presented in a few alternative formats than for the other interface details. The reason for this deviation is to allow the data to be applied broadly to many variations and to make the information easy and flexible to use. Balconies can be factored into U-value calculations using the following approaches.

1) U-value Approach

U-values of the opaque area of balconies are presented in the thermal performance data sheets in Appendix B. These U-values can be treated as its own wall assembly, or averaged into the adjacent assembly using an area weighted calculation. If using area weighted calculations, then the total projected area of the slabs need to be determined separately from the area of the adjacent walls.

2) Linear Transmittance without Area

Linear transmittances are provided in section 8.0 of Appendix B for balconies where it has been assumed there is no clear field. These values are essential a delta U that can be added to any adjacent wall assembly. However, in the calculations the clear wall heat loss should not include the area of the slabs. In the U-value equation given in section 1.25, the clear field U_o term should be corrected by multiplying it by the following factor, $A_{adjacent\ wall} / A_{total}$, where the area of the adjacent wall is the total area minus the area over the slab edge at the floor the floor glazing.

In each assembly where choosing one of these approaches in necessary, it has been indicated in the thermal performance results sheets in Appendix B.

1.3 Summary of the Thermal Performance Catalogue

1.3.1 Catalogue Breakdown

The catalogue prepared for this guide contains extensive thermal performance information on numerous common details, along with details intended to mitigate thermal bridging, including some emerging technologies and products. This data was calculated using the methodology from 1365-RP (including air films), as summarized in Section 1.2. The catalogue also contains thermal performance information from ASHRAE 1365-RP, along with other details previously analyzed by Morrison Hershfield Ltd. The catalogue is broken into two main sections:

- **Appendix A** contains an overview of the assemblies and interface details. This includes isometric drawings, dimensions and material properties.
- **Appendix B** contains the thermal performance information. This includes clear field, linear and point transmittance values, where applicable, along with overall U-values for the modeled assembly sizes and temperature indices.

For the catalogue, the details have been arranged first by construction type (steel framed, mass wall etc.), then by transmittance type (clear field, slabs, parapets, etc.). Table 1.1 shows how the catalogue is arranged. Table 1.2 summarizes the basic outline of what types of details are featured in the catalogue. A more detailed discussion on the catalogue information is given at the beginning of Appendices A and B.

Table 1.1: Catalogue Index

BC Thermal Study Catalogue
1. Window-wall
2. Conventional Curtain-wall
3. Unitized Curtain-wall
4. High Performance Curtain-wall
5. Steel Stud Construction
6. Concrete Construction
7. Wood Frame Construction
8. Doors and Balconies
9. Roofs

Table 1.2: Thermal Performance Catalogue Index

Detail Type	Detail Sub-Category
Clear Field Assemblies	wall, roof, spandrel section, cladding attachment method, insulation strategy
At-grade Transitions	exposed, exterior insulated, wood
Floor and Balcony Slab Transitions	exposed, under-insulated, shelf angle, manufactured thermal break, exterior insulated, wood
Glazing Transitions	un-insulated, misaligned insulation, efficiently aligned
Interior Wall Intersections	exposed, exterior insulated
Corners	interior insulated, exterior insulated
Parapets	exposed, under-insulated, manufactured thermal break, exterior insulated, wood
Roofs	penetrations, transitions
Structural Beams	through beam, manufactured thermal break

The beginning of Appendix B also includes a visual summary of the catalogue details. This includes a brief summary of each detail and key thermal performance values. These are arranged first by transmittance type (U, Ψ, χ) then by transmittance value. The inclusion of this visual summary is to facilitate faster navigation through the catalogue and provide another option for disseminating details for designers.

Many projects have architectural packages that can contain an overwhelming number of details (150+), and accounting for every interface detail can be time consuming and impractical. An intent of providing a catalogue is that by becoming familiar with the assemblies and interface details included here, designers will be able to estimate when interface details will have an impact on the building envelope and when similar details can be grouped together. As with any estimating process, good judgment will always be required.

1.3.2 Thermal Performance Categories

Previous work has been done (Janssens, et al., 2007) to categorize thermal transmittances in terms of performance in order to help designers compare details and set expectations for details that have not been explicitly modeled. All the details in this catalogue have been assigned a rating, from poor to efficient, based on the range of thermal transmittances between similar types of details. Due to the large number of slab, parapet and glazing transition details analyzed in preparation for this guide (approximately 30+ for each), separate linear transmittance ranges were created for each of those detail types. For other details, such as corners and partition walls, there are too few variations to create a performance range for that specific detail type. As such, they are all included in “Other Interface Details”. The ranges for Slabs, Glazing Transitions, Parapets and Other Interface Details are given in Tables 1.3, 1.4, 1.5 and 1.6 respectively. The visual summary, shown at the beginning of Appendix B, includes the performance categories within each detail summary.

Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

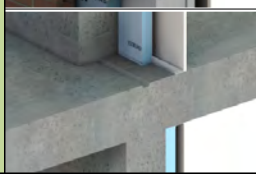
	Performance Category		**Description and Examples**	**Linear Transmittance**	
				Btu / hr ft F	**W / m K**
FLOOR AND BALCONY SLABS		**Efficient**	**Fully insulated with only small conductive bypasses** Examples: exterior insulated wall and floor slab.	0.12	0.2
		Improved	**Thermally broken and intermittent structural connections** Examples: structural thermal breaks, stand-off shelf angles.	0.20	0.35
		Regular	**Under-insulated and continuous structural connections** Examples: partial insulated floor (i.e. firestop), shelf angles attached directly to the floor slab.	0.29	0.5
		Poor	**Un-insulated and major conductive bypasses** Examples: un-insulated balconies and exposed floor slabs.	0.58	1.0

Table 1.4: Performance Categories and Default Transmittances for Glazing Transitions

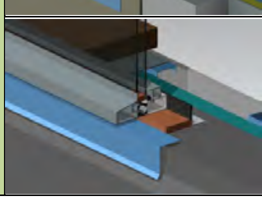
	Performance Category		**Description and Examples**	**Linear Transmittance**	
				Btu / hr ft F	**W / m K**
GLAZING TRANSITIONS		**Efficient**	**Well aligned glazing without conductive bypasses** Examples: wall insulation is aligned with the glazing thermal break. Flashing does not bypass the thermal break.	0.12	0.2
		Regular	**Misaligned glazing and minor conductive bypasses** Examples: wall insulation is not continuous to thermal break and framing bypasses the thermal insulation at glazing interface.	0.20	0.35
		Poor	**Un-insulated and conductive bypasses** Examples: metal closures connected to structural framing. Un-insulated concrete opening (wall insulation ends at edge of opening).	0.29	0.5

Table 1.5: Performance Categories and Default Transmittances for Parapets

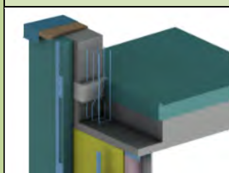
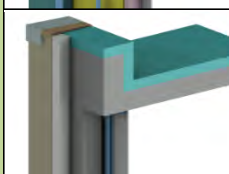
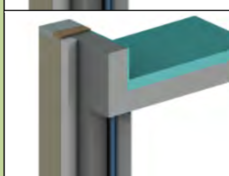
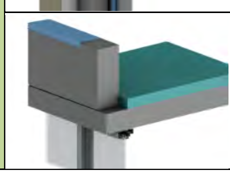
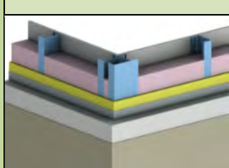
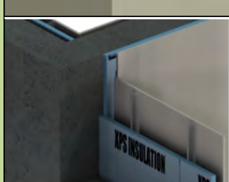
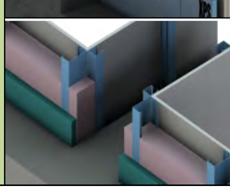
	Performance Category		Description and Examples	Linear Transmittance	
				$\frac{\text{Btu}}{\text{hr ft F}}$	$\frac{\text{W}}{\text{m K}}$
PARAPETS		Efficient	**Roof and Wall Insulation Meet at the Roof Deck** Examples: structural thermal break at roof deck, wood-frame parapet.	0.12	0.2
		Improved	**Fully Insulated Parapet** Examples: insulation wraps around the parapet to the same insulation level as the roof and wall.	0.17	0.3
		Regular	**Under-insulated Parapets** Examples: concrete parapet is partially insulated (less than roof insulation), insulated steel framed parapet, concrete block parapet.	0.26	0.45
		Poor	**Un-insulated and major conductive bypasses** Examples: exposed parapet and roof deck.	0.46	0.8

Table 1.6: Performance Categories and Default Transmittances for Other Interface Details

	Performance Category		Description and Examples	Linear Transmittance	
				$\frac{\text{Btu}}{\text{hr ft F}}$	$\frac{\text{W}}{\text{m K}}$
OTHER INTERFACE DETAILS		Efficient	**Minor Thermal Bridging at Miscellaneous Details** Examples: extra framing at corners of steel framed walls, wood-frame to foundation wall interface.	0.12	0.2
		Regular	**Moderate Thermal Bridging at Miscellaneous Details** Examples: insulation returns into a concrete shear wall, exterior insulated wall at interface with insulated footing.	0.26	0.45
		Poor	**Major Thermal Bridging at Miscellaneous Details** Examples: un-insulated concrete shear wall, exposed footing at exterior insulated wall with insulation below floor slab.	0.49	0.85

Rating details based on expected transmittance ranges has several uses:

1. Not every common interface detail has been evaluated and cataloged in this guide. Ranges help with estimating the order of magnitude of transmittance values for interface details that are not directly covered by the catalogue, without the need for further evaluation.
2. Some project specific interface details will still require further evaluation. The ranges for transmittances help set expectations for evaluating other interface details.
3. Ratings can establish default assumptions and/or set prescriptive requirements for the inclusion of interface details in codes and energy standards.
4. Similarly, ratings can establish values for the baseline buildings of the performance compliance paths in energy standards and/or performance rating programs (for example LEED).
5. Ranges for interface details can help set thermal performance targets for the building envelope early in design. When included with a preliminary energy model (before details are even chosen) the ranges can show what can be expected from the building envelope based on a given construction type.

1.3.3 OTHER SOURCES OF INFORMATION

While the catalogue provided with this guide is extensive, there are additional sources to find thermal performance data for clear field assemblies and linear and point transmittances. Here are a few examples:

- Appendix A of **ASHRAE 90.1 "Energy Standard for Buildings Except Low-Rise Residential"** (ASHRAE, 2010) contains several tables of thermal performance values for a variety of clear field constructions, including walls, roofs and floors for concrete, steel framed and wood framed constructions. The values for many of the exterior insulated structures assume continuous insulation and do not account for cladding attachments which interrupt the exterior insulation.

- **Manufacturers of proprietary systems**, such as structural cladding attachments or curtain-wall systems, often have thermal performance data of their products. Upon request they can provide designers with the information. However, be aware that different manufacturers may calculate thermal performance using various procedures, sometimes making it difficult to compare different systems appropriately. If the manufacturer does not provide a full report on their thermal performance values, it may be prudent to request further information.

- In the absence of more specific information, **ISO 14683:2007 "Thermal Bridges in Building Construction"** (CEN, 2007) provides generic linear transmittances for simplified constructions. This standard outlines the methods of calculating linear transmission used in the European standards and provides an Annex with default Ψ values for many of the common interface details. The default values are based on very basic geometric shapes representing building components, as shown in Figures 1.9 and 1.10, resulting in conservative transmittance values. For example, complex heat flow paths created by misaligned glazing thermal breaks or flashing are not captured by these values. This standard also provides multiple linear transmittances based on different dimensioning procedures. See the breakout box "A Note on Linear Length and Area Takeoffs for the Detail Oriented" in section 1.2.6 for more information.

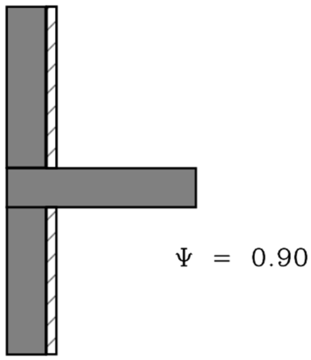


Figure 1.9: A reproduction of a simplified concrete wall assembly with interior insulation at through wall slab from ISO 14683:2007

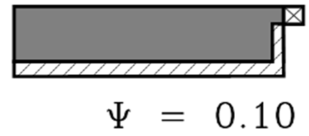


Figure 1.10: A reproduction of a simplified concrete wall assembly at a window jamb from ISO 14683:2007

1.4 EXAMPLE UTILIZATION OF THE CATALOGUE

In order to demonstrate how to utilize the catalogue in calculating overall U-values for a building, the following is a step-by-step example for a common Vancouver residential high-rise building.

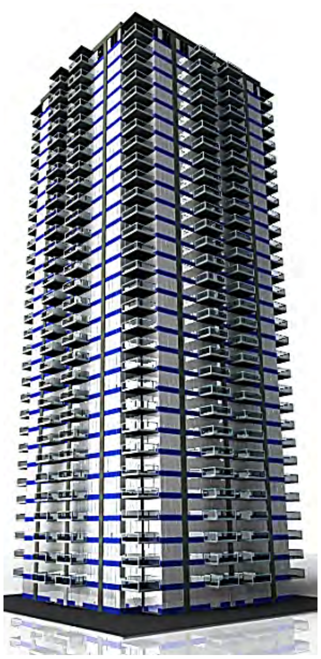


Figure 1.11: Example High-Rise MURB with 60% glazing

Example: *A designer wishes to find the overall U-value for each construction type for a High-Rise Multi-unit Residential Building with 60% glazing.*

The building (illustrated in Figure 1.11) is concrete construction, with an R-11 (RSI-1.94) interior insulated concrete wall between window-wall sections. The window-wall sections include a glazed section (U-0.4, USI-2.3) and spandrel section with R-8.4 (RSI-1.48) insulated backpan. The roof contains an R-20 (RSI-3.52) insulated deck that has several beam penetrations and curbs to support an architectural feature. There are balconies, exposed concrete slab edges and window-wall bypasses. All details are typical and assumed to be contained within an architectural drawing package.

Step 1: Determine How to Divide Up the Building

In calculating building envelope U-values, first it should be known how the U-values will be used. U-values can be calculated for different areas depending on how the U-value will be utilized or level of detail required. For example, the building envelope performance could be divided by zone to find specific zone heating loads, by construction type for whole building energy analysis or kept as one value for the whole building for preliminary design. The methodology to find the different U-values are the same and it is up to the judgment of the designer on what they require.

In this example, the designer chooses to divide the building by construction type.

Step 2: Determine Clear Field Assemblies

The construction types can be determined through the clear field assemblies, which can be found from wall/roof/floor schedules, as shown in Figure 1.12, but also by sorting through the elevations and detail drawings. There may be multiple clear field assemblies for a single construction type (i.e. several steel stud assemblies), but if they are similar enough in thermal transmittance, with good judgment they can be combined and considered one assembly.

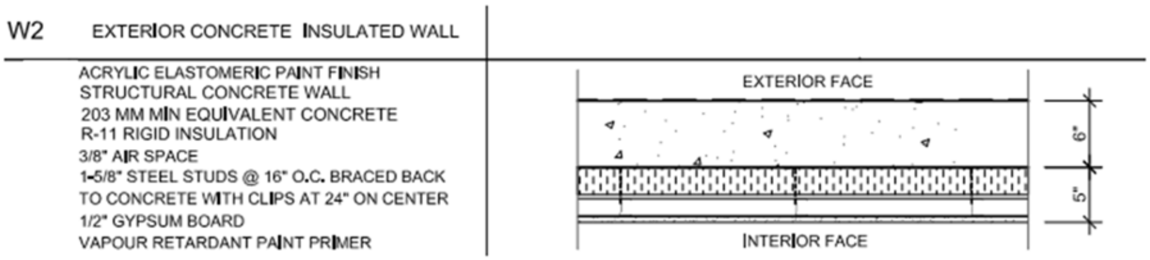


Figure 1.12: Example concrete clear field wall assembly

For this example, from the architectural drawings, the designer finds there are three distinct construction types in the wall and roof schedules: Concrete Wall, Concrete Roof and Window-wall Spandrel.

Step 3: Determine Linear and Point Details

After determining the clear field assemblies, the types of linear and point details need to be found. In architectural drawings, these can be found through elevations, plans and detail drawings, as shown in Figures 1.13 and 1.14.

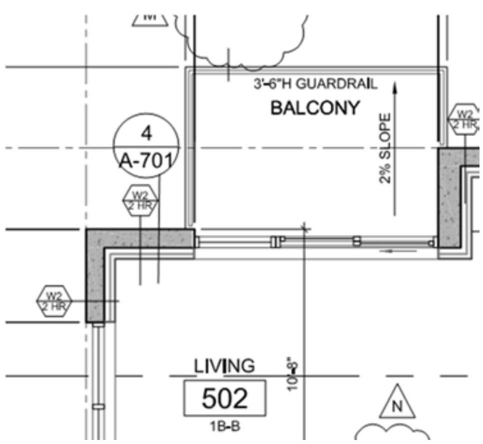


Figure 1.13: Exposed Floor Slab in Plan 4/A701

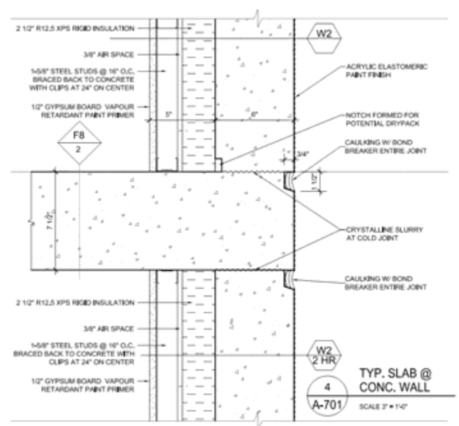


Figure 1.14: Exposed Floor Slab detail 4/A701

When dividing by construction type, the interface details can also be divided in the same way and can be assigned to specific clear field assemblies. For each clear field assembly there will be a set of linear and/or point details associated with it. For transitions between different clear field assemblies (such as a parapet transition between wall and roof) it is up to the designer to choose which assembly to assign the heat loss to.

For this example, an isometric floor plan is given in Figure 1.15. From the architectural drawings, the designer determines there are several standard details and assigns them to the concrete wall, the window-wall spandrel or the roof. In this case, the designer assigns the parapets to the walls. In the drawings, the designer finds there are only balcony slabs at the spandrel sections. The transmittance types are summarized in Table 1.7. For the simplicity of this example, other miscellaneous details have been omitted.

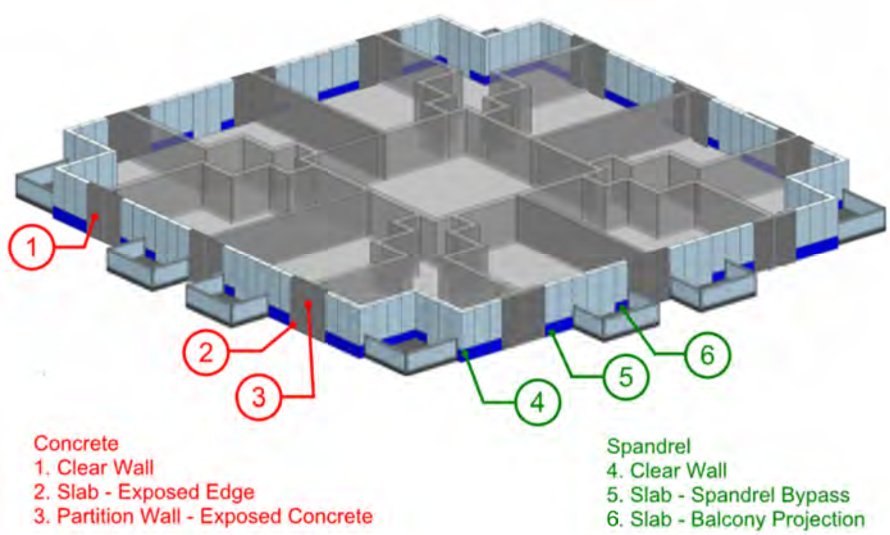


Figure 1.15: Example building typical floor plan

Table 1.7: Summary of Steps 1-3 for example building

Step 1-2	Step 3
Transmittance Type	
Concrete Wall	Clear Field – Concrete Wall
	Parapet – Exposed Concrete
	Slab - Exposed Concrete Edge
	Slab - At Grade Transition
	Partition Wall - Exposed Concrete
Window-wall Spandrel	Clear Field – Spandrel
	Parapet – Partially insulated by Spandrel
	Slab – Spandrel Bypass
	Slab – Spandrel with Balcony projection
	Slab - At Grade Transition
Roof	Clear Field – Roof
	Curb – Uninsulated
	Point Penetrations – Structural Beams

Step 4: Determine Area and Length Takeoffs

With the types of transmittances (clear field, linear and point) found, the area, lengths and number of instances should be determined. Information on takeoffs is given in section 1.2.6. Areas for the clear field can typically be easiest to determine from elevation drawings. Lengths for slabs, parapets and other horizontal linear details can be found through plans, while lengths for vertical linear details (such as corners) can be found in the elevations. An example takeoff for slab edges is shown in Figure 1.16.

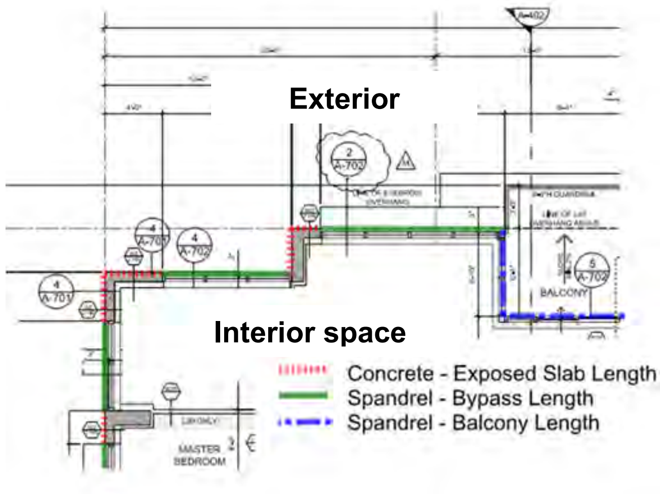


Figure 1.16: Example slab length takeoff

Using the floor plans and elevations, the designer determines the appropriate takeoffs for each detail they determined in Table 1.7. Using the elevations, the areas of the clear fields (including areas over the slab edges) are found. The slab edge lengths for a single floor are calculated, and then are multiplied by the amount of similar floors in the building. Each of the partition walls are found to extend the height of the building. The parapet lengths and curb lengths and number of beam penetrations are found using the roof plan and the at-grade transitions are found using the ground floor plan. Takeoff areas and lengths for this example are given in Table 1.8.

Step 5: Determine Clear Field, Linear and Point Transmittances

Thermal performance data for clear field, linear and point details can be found in the catalogue provided with this guide, or through other sources (outlined in section 1.3.3). The project specific interface details can be matched up with the catalogue details in Appendix A and the thermal values are given in Appendix B. If a specific project detail cannot be found in the catalogue, judgment will be required to estimate the thermal performance by comparing similar details or by using the ranges in section 1.3.2. If that cannot be done with certainty, then further modeling may be necessary.

For this example, the designer matches as many clear field assemblies and interface details to the catalogue as they can. The designer first looks at the visual summary in Appendix B, then narrows down to the specific details. The designer finds the following:

- *For the concrete wall clear field and interface details, the designer finds appropriate matching details in Appendix A.6 – Mass Walls and the thermal values for those details in Appendix B.6, except for the at-grade transition.*

- *The designer finds an appropriate linear transmittance for the concrete at-grade transition in ISO 14863.*
- *For the spandrel wall clear field and interface details, the designer finds appropriate matching details in Appendix A.1 – Window-wall and Appendix A.8 – Balconies and Doors, along with the thermal data in Appendix B.1 and B.8, except for the at-grade transition.*
- *The designer estimates the at-grade transition by comparing their project detail to a similar conventional curtain-wall Detail 2.5.1.*
- *The designer finds matching roof details in Appendix A.9 – Roofs along with the matching thermal data in Appendix B.9.*
- *The designer decides not enough information is available to estimate the roof penetrations and decides to have that detail modeled.*

Detail references and transmittances for this example are given in Table 1.8.

Step 6 (Optional): Calculate Individual Transmittance Heat Flow

While not necessary to calculate the overall U-value, it may be advantageous for designers to calculate the individual heat flows associated with specific details to help make better design decisions and identify details that should be targeted. Recognizing components of the U-value equation given in section 1.2.5, the individual heat flows can be calculated using the following:

- Clear Field Heat Flow = $U_o \cdot A$
- Linear Transmittance Heat Flow = $\Psi \cdot L$
- Point Transmittance Heat Flow = $\chi \cdot$number of occurrences

For this example, the designer calculates the heat flow through the individual details to see which interface details have the largest impact on thermal performance. From that analysis the designer is able to determine which details should be a priority to improve. Individual heat flows for this example are given in Table 1.8.

Step 7: Calculate Overall U-Value

With all the transmittance values and takeoff areas/lengths known, the overall Wall/Roof U-values can be calculated using the equation given in section 1.2.5.

$$U_T = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi)}{A_{Total}} + U_o$$

If the individual heat flows have already been determined in Step 6, then all of the heat flows can be summed together and divided by the total opaque area (in this case, the clear field area) to get the overall U-value that includes the effects of thermal bridging at interface details.

The designer calculates the overall U-values for each construction type, along with an overall Opaque Wall U-value and Opaque Roof U-value separately. The summary of all steps for the example building is given in Table 1.8 and 1.9 for the walls and roof respectively.

Table 1.8: Summary of Calculation Steps 1-7 for Example Building Opaque Wall

Step 1-2	Step 3	Step 4	Step 5		Step 6-7	
Transmittance Type		Quantity	Detail Ref.	Transmittance	Heat Flow (W/K)	% of Total Heat Flow
Concrete Wall	Clear Field	2987 m²	6.2.2	0.42 W/m²K	1254	16%
	Parapet	27 m	6.5.3	0.78 W/mK	21	<1%
	Exposed Floor Slab	1090 m	6.2.5	1.00 W/mK	1085	14%
	At Grade Transition	27 m	ISO-14863	0.75 W/mK	20	<1%
	Partition Wall	1315 m	6.2.2	0.67 W/mK	876	11%
Overall Concrete Wall U-value, BTU / hr ft² °F (W/m²K)					**0.192 (1.09)**	
Overall Concrete Wall R-value, hr ft² °F/ BTU (m²K/W)					**5.2 (0.92)**	
Window-wall Spandrel	Clear Field	1792 m²	1.1.1	1.07 W/m²K	1917	24%
	Parapet	82 m	1.3.2	0.72 W/mK	59	<1%
	Slab Bypass	1635 m	1.2.1	0.58 W/mK	945	12%
	Balcony Slab	1635 m	8.1.9	1.11 W/mK	1815	23%
	At Grade Transition	82 m	2.5.1 (est.)	0.86 W/mK	70	<1%
Overall Spandrel Wall U-value, BTU / hr ft² °F (W/m²K)					**0.472 (2.68)**	
Overall Spandrel Wall R-value, hr ft² °F/ BTU (m²K/W)					**2.11 (0.37)**	
Total (W/K)					**8063**	**100%**
Overall Opaque Wall U-value, BTU / hr ft² °F (W/m²K)					**0.297 (1.68)**	
Overall Opaque Wall R-value, hr ft² °F/ BTU (m²K/W)					**3.4 (0.59)**	

Table 1.9: Summary of Calculation Steps 1-7 for Example Building Opaque Roof

Transmittance Type		Quantity	Detail Ref.	Transmittance	Heat Flow (W/K)	% of Total Heat Flow
Roof	Clear Field	743 m²	9.2.2	0.27 W/m²K	200	82%
	Curbs	20 m	9.2.2	0.93 W/m K	19	8%
	Beam Penetrations	#20	Modelled	1.2 W/K	24	10%
Overall Roof U-value, BTU / hr ft² °F (W/m²K)					**0.058 (0.33)**	
Overall Roof R-value, hr ft² °F/ BTU (m²K/W)					**17.3 (3.05)**	

Even though it takes up less area of opaque wall than the concrete, the designer can see that the largest amount of heat flow is associated with the spandrel section clear field, but the heat flow through the window-wall bypass and the balconies is also significant.

1.5 INPUTTING THERMAL VALUES INTO ENERGY MODELS

Determining overall building performance, including the combined interaction between envelope, mechanical and electrical systems, is often termed “whole building energy analysis” and is often assessed using computer simulation and is used for multiple purposes, including:

- Design decision making through parametric analysis, by considering the energy and cost impact of design decisions to reduce energy or meet code
- Demonstrating compliance with energy codes
- Comparing a proposed building to a reference building for green building rating systems (LEED, Green Globes, etc.)
- Estimating energy use in new or existing buildings
- Estimating the impact of operational improvements or capital investments in existing buildings
- Heat loss calculations for mechanical system sizing

One of the main drivers for creating this guide was to provide more accurate thermal values and a methodology for designers to assist in creating more precise energy models.

Currently, there are few energy modeling programs that allow linear transmittance values to be input directly into energy simulations. While this feature is being considered for development for common building energy simulation software, at the moment this ability is not widely available. Thermal transmittances are either directly inputted as wall, roof or floor U-values or determined by using construction layers to build up the building envelope assemblies. For either case, the overall U-value that includes the effects of linear and points transmittances must first be determined without the assistance of the energy modeling software to ensure that the correct thermal transmittances will be processed by the model.

It is important to emphasize that air leakage and dynamic thermal responses are accounted for by separate functions in typical whole building energy models. Thermal bridging is accounted for only in the thermal transmittances that are processed by the energy model. See Appendix C for an explanation of how energy models take into account thermal mass separately from thermal transmittances.

Many modeling programs use construction layers to build up the building envelope assemblies based on material properties. To account for thermal bridging, all the material properties should be left as is, while only the insulating layer R-value should be de-rated such that the correct overall U-value determined from calculation is matched and output by the software. This method allows for the functions that account for thermal mass to be approximated by the software.

Example: *a section of concrete wall with R-15 exterior insulation contains a balcony slab and is calculated to have an overall U-value of U-0.16. The energy modeling program being used requires construction layers as the inputs. The layers are input with default values for the air films, cladding, airspaces, concrete and interior finishes and the simulation output shows a U-value of U-0.05. The exterior insulation R-value is edited and decreased from R-15 such that in the simulation output, the U-value for the overall wall assembly matches U-0.16.*

One final note on model inputs, the clear field U-values given in the thermal performance catalogue in this guide are based on the ASHRAE 1365-RP methodology, which include air films. Many energy modeling programs calculate air films separately. The air films for the modeled details in this guide are listed with the material properties in each of the details in Appendix A. The thermal resistance of these air films may need to be subtracted out before entering R- or U-values into an energy modeling program.

1.6 REFERENCES

ASHRAE. (2010). ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Rerigerating and Air-Conditioning Engineers Inc.

ASHRAE. (2013). Handbook of Fundamentals. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

CEN. (2007). *ISO 14683 Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values.* Brussels: European Committee for Standardization.

Janssens, A., Van Londersele, E., Vandermarcke, B., Roels, S., Standaert, P., Wouters, P., & A, A. (2007). Developement of Limits for the Linear Thermal Transmittances of Thermal Bridges in Buildings. *Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference* (p. Paper 182). Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Mitchell, R., Kohler, C., Curcija, D., Zhu, L., Vidanovic, S., Czarnecki, S., . . . Huizenga, C. (Rev 2013). *THERM 6.3/WINDOW 6.3 NFRC Simulation Manual.* Berkeley: University of California.

Morrison Hershfield Ltd. (2011). *ASHRAE 1365-RP Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings.* Atlanta, GA: American Society of Heating, Refrigerations and Air-Conditioning Engineers Inc.

PART 2
ENERGY SAVINGS AND COST BENEFIT ANALYSIS

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2.1 OVERVIEW

Part 1 of this guide addresses the impact of thermal bridging on the thermal performance of building envelope assemblies. Part 2 assesses the impact and significance of thermal bridging from the broader perspective of whole building energy use and the cost effectiveness of different approaches to mitigating thermal bridging.

An energy analysis of several archetypal buildings was performed in conjunction with evaluating incremental construction costs for several different scenarios of interface details. The methodology for whole building energy analysis is described below, followed by construction cost estimates. Finally, the energy use and construction costs are combined in a cost-benefit analysis associated with addressing (or not addressing) thermal bridges.

Throughout Part 2, several fundamental questions are addressed:

1. What is the difference between energy consumption for whole building energy models that do and do not account for the extra heat flow through thermal bridging at interface details?
2. What are the incremental costs associated with mitigating thermal bridges?
3. What is the payback for improving the thermal performance of the building envelope and mitigating thermal bridges?

Part 2 gives an overview of the cost-benefit analysis methodology with the intent of showcasing how the methodology can be used to determine order of magnitude estimation of the cost effectiveness of mitigating thermal bridging to reduce energy consumption in buildings. To demonstrate the methodology, the cost-benefit analysis was performed on several archetypal buildings in British Columbia for a variety of design scenarios. Key findings and discussion from the cost-benefit analysis performed for this guide can be found in Part 3 – Significance and Insights.

Part 2 is intended to demonstrate to all stakeholders how the impact of thermal bridging can be related to building energy use and how incremental construction costs can be evaluated for mitigating thermal bridging in construction.

2.2 WHOLE BUILDING ENERGY USE

2.2.1 ASSESSING WHOLE BUILDING ENERGY USE

Demonstrating the effects of thermal bridging on whole building energy use is an integral part of this study, as it provides greater context to the building envelope thermal performance analysis. While U-values are important for determining compliance with prescriptive codes and comparing alternate envelope solutions, the values are often a means to answering the larger question of building energy consumption.

A building's energy use, and the influence of building envelope U-values on that energy use, depends on a number of parameters, for example:

- Regional Climate
- Building Type, which determines occupancy uses and densities, internal gains and various schedules
- Building Envelope Performance, including envelope U-values and air tightness
- Mechanical Systems, including those for space and ventilation heating and cooling, service hot water heating, and auxiliary equipment such as pumps and fans
- Electrical Systems, including lighting and plug loads

The impact of envelope thermal transmittance on whole building energy use was quantified for a set of archetypal buildings, discussed in the following section, that cover the majority of the BC market. Each archetypal building represents a different set of parameters that result in varying impacts of the envelope U-value on building energy use. This energy use analysis sets the basic framework for the cost-benefit analysis in section 2.4.

2.2.2 Building Archetypes and Modeling Variables

Whole building energy analysis was performed on eight archetype buildings, each representing a different building sector. The characteristics of the archetype buildings were selected based on current BC design and construction practice. The eight archetype buildings that were analyzed are detailed in Appendix C and listed below:

- High-Rise Multi-unit Residential
- Low-Rise Multi-unit Residential
- Hotel / Motel
- Institutional
- Secondary School
- Commercial Office
- Community/Recreation Centre
- Non-Food Retail

Each archetype building was analyzed for two glazing ratios, which varied by sector and three climates representing the major climate zones in the province. The climates modeled were:

Vancouver *Lower Mainland BC, Cool-Marine Climate Zone*	**Summerland** *Interior BC, Cool-Dry Climate Zone*	**Prince George** *Northern BC, Very Cold Climate Zone*

The thermal resistance of the wall was varied for each archetype building, glazing ratio and climate zone while all other parameters of the building were kept constant. In general, the R-values input into the model for the walls ranged from R2.5 to R20. The thermal mass of building materials was also considered and that analysis, along with more detailed modeling parameters, is provided in Appendix C.

2.2.3 IMPACTS OF THERMAL PERFORMANCE ON WHOLE BUILDING ENERGY USE

The energy use versus envelope R-value was plotted on a curve to show the impact of building envelope thermal transmittance on whole building energy use. An example is shown in Figure 2.1. The energy curve for each building type, climate zone and glazing ratios are given in Appendix C. The curves in Appendix C are also separated by electrical or natural gas use per building. The curves provide an easy reference which can be used to show:

- The energy use overlooked by ignoring the impact of thermal bridges associated with interface details. This comparison is done by comparing the energy use at an R-value that considers only the clear field thermal resistance to the effective R-value that accounts for interface details. This comparison is intended to highlight the optimistic view of current energy modeling practice to more realistic building energy consumption.
- The energy use associated with improving building envelope thermal performance by more thermally efficient interface details when they have been considered in a whole building energy analysis.

These curves can be created for any specific project design. Figure 2.1 shows the electrical energy use curve for a high-rise MURB with a 40% glazing ratio in Vancouver, BC that is heated with electric baseboards.

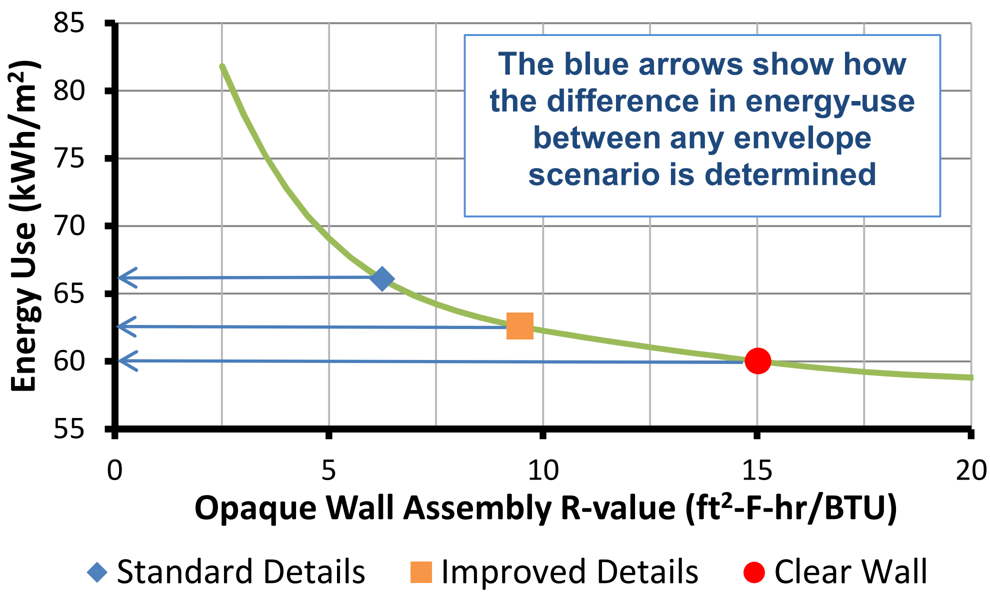


Figure 2.1: Annual Electrical Energy for a 40% Glazed High-Rise MURB in Vancouver, Heated with Electric Baseboards

From Figure 2.1, there are several things to note. First, the curve (in green) shows that there are diminishing returns on energy savings with increasing opaque wall R-value. In this example building, after an overall opaque wall R-value of 15, there is very minimal benefit for further improving the building envelope thermal performance because the reduction in energy use is marginal. The shape of this curve and the severity of the diminishing returns depend on the climate, glazing percentage and other parameters mentioned in section 2.2.1.

The next thing to note is where an opaque wall design falls on the curve when thermal bridges have or have not been considered. As part of this example, Figure 2.1 shows three wall R-value scenarios, each a separate point on the curve:

- Only the clear wall is considered (red circle)
- The clear wall is considered along with thermal bridging through standard details (blue diamond)
- The clear wall is considered along with improved details that minimize thermal bridging (orange square)

The location of each of these R-value points depends on the building design, however, they can be found for any design scenario by following the methodology in Part 1 of this guide. When only the clear wall values are considered, the energy use typically sits at the flat end of the curve. For an energy modeler or architect, this gives the false impression that the building envelope, as designed, is providing its maximum potential in reducing space heating energy and no other improvements are needed. In reality, when thermal bridging is fully taken into account, the actual opaque wall R-value can be much lower and the energy use can sit at the steeper end of the curve. Recognizing this higher energy use provides an incentive to improve the building envelope thermal performance by mitigating thermal bridging that is otherwise overlooked. In using improved details that minimize thermal bridging, it can be seen that the energy use can drop significantly and approach the flat end of the curve, closer to the clear wall or “idealized” value.

The opaque envelope has varying potential for energy savings depending on the building type and climate. These relationships are summarized in Appendix C. The reduction in energy use related to the building envelope is also related to the utility (electricity or gas) that provides space heating. This is typically natural gas except for the low-rise and high-rise MURB archetypes. Several building types also show modest changes in energy use in the non-heating utility, which is a result of changes in ancillary energy use, such as fans, pumps, etc. For example, reductions in heating may lead to slight reductions in fan and pump energy. Some anomalies in energy use are evident for certain archetypes, notably institutional, where building loads are dominated by internal gains and ventilation, rather than envelope losses.

The energy use curves for each of the building archetypes are used in the cost-benefit analysis to compare the reduction in energy use (and thus, energy cost) between different building envelope scenarios. This in turn is used to determine the payback for each scenario, for example mitigating thermal bridging at interface details, higher performance assemblies, or the more conventional method of adding more insulation. The methodology of the cost-benefit analysis is presented in section 2.4.

2.3 CONSTRUCTION COSTS

Construction cost estimates for the building envelope assemblies that are covered by the guide were provided by a general contractor in preparation of this guide. Assembly costs were provided for low- and high-rise construction for three insulation levels. The cost estimates are for installed assemblies that include assumptions for installation access (for example exterior access by swing stage) and material and labour for all components related to the assembly from the exterior façade to the interior drywall. Labour and materials and incremental costs of non-standard details were also provided. Examples of incremental costs include manufactured thermal breaks, extra parapet insulation, and exterior insulation at footings.

The general contractor arrived at these estimates through consultation with sub-trades, review of costs on past projects, and consultation with manufacturers. A detailed summary of the construction cost estimates are found in Appendix D.

Figure 2.2: Mid-Rise Construction in Vancouver

The construction assembly costs are subjective and are order of magnitude estimates. There are many variables and constraints on real projects that will overshadow some of the estimated cost differences between the assemblies. The main point to remember is that construction costs vary quite widely in practice. This variability is part of the reason that construction projects typically have a bid process, where there can be a big difference between the highest and lowest bid. Consideration of the nature of this analysis and the fluidity of construction costs is required to reach meaningful conclusions. The construction cost estimates utilized by this guide are broad cost estimates with more uncertainty than a Class D estimate, because the estimates were not arrived for a specific building nor is there a comprehensive list of requirements to base assumptions. Accordingly, order of magnitude means that the construction costs estimates are +/- 50%.

Comparisons of energy use and construction costs are made for different types of assemblies in the cost-benefit analysis in section 2.4. For example, poured-in-place concrete is compared to precast concrete panels, because precast panels inherently have less thermal bridging at floor slabs than interior insulated poured-in-place concrete walls. However, the construction estimates are too general to make broad conclusions between competing assemblies. Moreover, the construction costs do not consider all synergies that go into a design, such as shear walls that are part of the building envelope. Sweeping conclusions should not be made, such as precast concrete panels should always be used over poured-in-place concrete because the construction costs are less and you get better performance. Project teams can choose any method of construction for any number of reasons.

The incremental costs were arrived at by comparing a detail that was deemed standard practice to a non-standard detail.

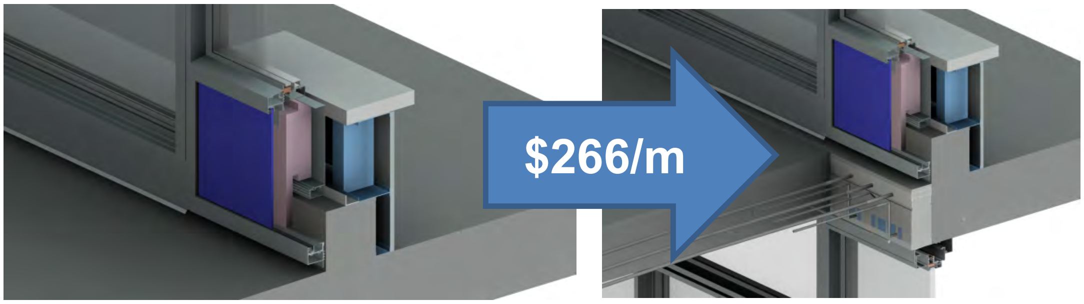
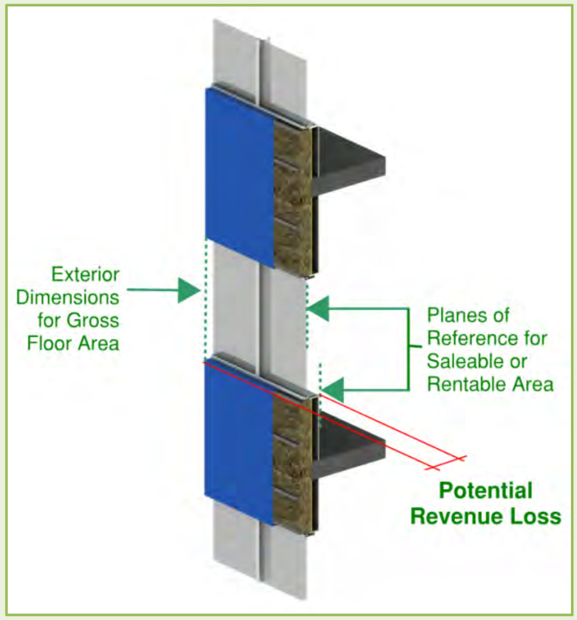


Figure 2.3: Approximate costs to move from a continuous concrete balcony to a thermally broken concrete balcony

The estimates for new technologies, such as manufactured thermal break solutions, vary but appear to be priced at a premium. However, opportunities for this kind of product to be more cost effective in the future are likely as industry in BC becomes more familiar with the new technology.

What ultimately matters to developers is a level playing field and opportunities to choose the most effective method to comply with code while balancing factors that can affect the success of a project by a greater measure, (for example, suitable granite countertops or great views of the mountains). It is a hard decision to invest in improving the building envelope performance when any difference between your building and a neighouring site in energy efficiency may not be easily recognized by consumers, especially when code does not require a design team to seriously consider thermal bridging. Code requirements that force major thermal bridges to be accounted for during design will be more effective in transforming the market than relying on the “fluid” analysis of cost benefits of new technologies. The market will naturally gravitate to cost-effective solutions within the margins of accepted practice.

Floor Space Ratios and Costs for Thicker Walls to Accommodate Extra Insulation



Some municipalities have a metric in zoning bylaws to control development density by limiting the ratio of a building's total floor area (gross floor area including exterior walls based on exterior dimensions) to the area of the land parcel upon which it is built. This metric is referred to as the **Floor Space Ratio** (**FSR**) in British Columbia. In densely populated jurisdictions with FSR zoning requirements, developers typically strive to maximize the saleable or rentable floor area for a fixed overall gross floor area. There are differences in what areas are included or excluded in the calculation, but in principle, developers will try to maximize the building's saleable or rentable floor area. With the external building dimensions fixed by the FSR, an increase in thickness of walls to accommodate extra insulation can in theory affect the saleable floor or rentable area. However, saleable or rentable floor area can be measured at either the glass, interior of wall, or some other defined plane, depending on the methodology followed by the quantity surveyor. The reference point can be dependent on factors like whether there is more or less glass compared to the opaque wall area in the vertical floor-to-ceiling dimension.

For interior insulated assemblies, such as architectural poured-in-place concrete walls with "continuous insulation," the saleable or rentable floor area may or may not be impacted by extra insulation thickness depending on the plane of reference for establishing the saleable or rentable space. The saleable or rental floor area could be impacted by extra insulation for exterior insulated assemblies but municipalities like the City of Vancouver have recognized this possibility and have enacted FSR exclusions to make sure there is less of a disincentive for extra insulation. In the Lower Mainland of BC, where allowable FSR's come into play, the floor area is likely largely dominated by the glass, since glazing ratios are high.

In conclusion, there could be a cost associated with thicker walls to accommodate extra insulation, in some jurisdictions, for some types of construction. Conceivably this could become more of an issue if energy performance became more of a driving factor, glazing ratios come down, and insulation levels could be reduced for the reward of high overall building envelope thermal performance through efficient detailing. However, the cost impact of increased wall thickness to accommodate higher insulation levels does not appear to be a significant driving factor in BC. Moreover, there is no tangible rule of thumb to the incremental cost per area and the cases that extra costs might apply. In section 3.4, this concept is illustrated by using a cost of \$150/ft^2 for extra wall thickness but this extra cost was not used for all the extra insulation scenarios in the cost benefit analysis in section 2.4.

2.4 COST BENEFIT

2.4.1 METHODOLOGY

This guide presents the cost benefit to improving the opaque building envelope through broad strategies that include improving interface details, increasing insulation levels, and selecting assemblies that characteristically have less thermal bridging than other types of construction. The analysis was performed on the chosen archetypal buildings using the energy use curves developed in section 2.2, with the construction costs from section 2.3 for a variety of construction scenarios. These scenarios include:

1. **The Impact of Interface Details**: the energy-use of buildings without thermal bridging at interface details, per U-values required by codes and standards, is compared to more realistic expectations for how buildings are commonly constructed in BC.

2. **Thermal Bridging Avoidance**: some thermal bridging can be simply avoided by better design. The impact of better design is evaluated by looking at the impact of details that are often unnecessary, such as concrete shear walls that intersect with the exterior walls, and selecting assemblies that inherently have less thermal bridging.

3. **The Effectiveness of Adding More Insulation**: current trends of energy codes and standards are to simply require more insulation be added to wall assemblies. The effectiveness of the "more insulation is better" strategy provides a benchmark for the cost effectiveness of solutions that are happening in practice to meet current codes. The "more insulation is better" strategy is compared to the cost benefit of what solutions will likely be explored more often by industry if thermal bridging was thoroughly addressed by codes and standards.

4. **Ranking of Opaque Thermal Performance:** current trends in BC are to increase glazing performance, which is resulting in triple glazing being considered more often than in the past. The cost benefit of triple glazing provides another benchmark, with the addition of more insulation, to the cost effectiveness of solutions already accepted by industry.

These broad scenarios were evaluated for all the building types, glazing ratios, and climates identified in section 1.2. By determining the overall thermal performance of the opaque envelope (U- and R-values) for each scenario following the steps in Part 1, the total building energy use was found using the curves determined in section 2.2 (and Appendix C). The energy costs and construction costs for each scenario were then determined. Incremental energy and construction costs were then compared to determine a payback period for various building envelope scenarios. A summary of the complete cost-benefit analysis can be found in Appendix E. The key findings from this cost-benefit analysis are presented in Part 3. A general example of the cost benefit process is given in the next section.

2.4.2 Example Cost Benefit Procedure

The following is an example on how to review and assess other detail permutations of interest in a cost-benefit analysis using the procedures and data contained in this guide.

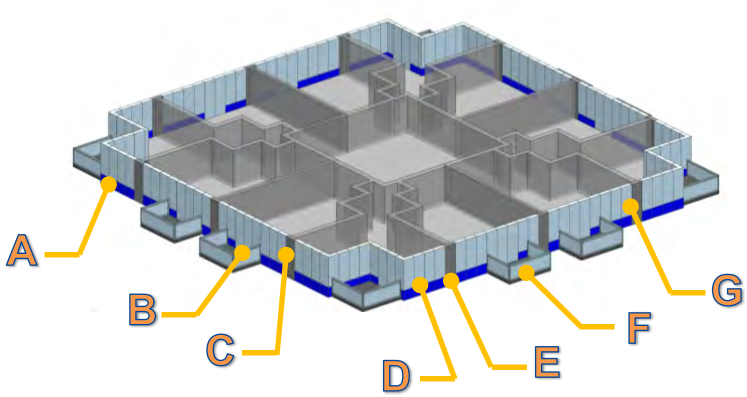
Example: *Cost Benefit of Improving Practice for Multi-unit Residential Building with 70% Glazing in Vancouver for Concrete Construction, shown in Figure 2.4. This is similar to the example building in section 1.4, however, with different dimensions and interface details.*

Figure 2.4: High-Rise MURB Example Building

The steps of the cost benefit are:

1	Determine the wall areas and lengths of the interface details
2	Determine overall U-value
3	Determine construction costs
4	Relate U-value to energy savings
5	Determine incremental energy savings and incremental costs
6	Determine Simple Payback

Step 1. The geometry analyzed for the cost-benefit analysis is based on the building archetypes utilized for the energy modeling. However, for some cases more complicated geometry was used to better reflect common practice in terms of U-value and costs. In this example, the multi-unit residential building incorporated some articulating architecture to illustrate the impact of corners and to reflect a real high-rise residential architecture in BC. A typical floor illustrating the clear wall and interface detail quantities are shown in Figure 2.5.



Opaque wall area
A. Window-wall spandrel
B. Curb at sliding door
C. Concrete wall

Floor slab interface detail
D. At window-wall spandrel bypass
E. At concrete wall
F. At balcony

Glazing interface detail
G. Vertical

Figure 2.5: High-Rise MURB Layout with detail listing

Steps 2 and 3. The overall U-value and construction costs are determined using the quantify takeoffs from step 1. The cost calculation is simply an extension to the procedure outlined in Part 1 to determine the overall U-value. An example table showing the determination of the overall U-value and construction costs follows.

		Step 1		Step 2			Step 3	
Transmittance Type		Quantity (m^2 or m)	Detail Ref.	Trans-mittance (W/m^2K or W/mK)	Heat Flow (W/K)	% Total	Unit Rate ($/quantity)	Total Cost ($)
Clear Wall	Spandrel	2090 m^2	1.2.1	1.21	2529	33%	580	$1,212,200
Clear Wall	Door Curb + Balcony Slab	209 m^2	8.13	2.86	598	8%	580	$121,373
Clear Wall	Concrete	886 m^2	6.2.2	0.42	372	5%	674	$597,164
Parapet	At Concrete	11 m	6.5.3	0.78	9	0%	-	-
Parapet	At Window-wall	117 m	1.3.1	0.81	94	1%	-	-
Floor	Window-wall By-pass	1768 m	1.2.1	0.51	900	12%	-	-
Floor	Window-wall At Balcony	679 m	8.1.9	1.13	767	10%	-	-
Floor	At Concrete Wall	312 m	6.2.5	1.00	310	4%	-	-
Glazing Interface	Vertical Interface	1975 m	6.3.2	0.56	1106	17%	-	-
Interior Wall	Concrete Shear Wall	988 m	6.2.2	0.67	658	9%	-	-
At Grade	At Window-wall	95 m	2.5.1	0.86	81	1%	-	-
At Grade	At Concrete Wall	11 m	ISO-14863	0.75	8	0%	-	-
At Grade	At Sliding Door	22 m	2.5.1	0.86	19	0%	-	-
Total					**7452**	**100%**	**$ 1,930,737**	
Overall Opaque U-value, BTU / hr ft^2 °F (W/m^2K)					0.41 (2.34)			
Effective R-value, hr ft^2 °F/ BTU (m^2K/W)					2.4 (0.43)			

Steps 4 to 6. The overall U-value is related to the energy savings using the curves that are discussed in section 2.2.3. Then the incremental energy savings and costs are determined and are utilized to calculate the simple payback. An example showing the determination of the simple payback for the high-rise MURB example is shown below.

	Step 4				Step 5			Step 6
Case	U-value		Total Energy		Annual Energy Savings		Incr. Cost	Pay Back (yrs)
	$\frac{W}{m^2K}$	% Red.	$\frac{kWh}{m^2}$	Cost	$\frac{kWh}{m^2}$	Cost	$	
ASHRAE 90.1-2010 Zone 5 (Assembly Only)	0.45	-	193.3	$255,729	-	-	-	-
NECB 2011 Zone 5 (Assembly Only)	0.28	-	192.1	$252,888	-	-	-	-
Base Case: Standard Assemblies + Details	2.07	-	203.6	$278,536	-	-	-	-
More Insulation for Concrete Wall; R-10 i.e. + R-12	2.03	2%	203.4	$278,130	0.16	$406	$15,062	37
Avoid Shear Wall Intersection	1.86	10%	202.7	$276,114	0.97	$2,421	-	0
Avoid Shear Wall Intersection and more Insulation	1.83	12%	202.5	$275,664	1.15	$2,871	$15,062	5
Improve Window-wall spandrel, more insulation, and thermally broken balconies and parapet	1.25	40%	199.5	$267,443	4.45	$11,092	$424,175	38

Detailed Economic Analysis

Currently natural gas prices are relatively low in BC compared with electricity rates. Although the rates vary somewhat by building size and geographic area, they are relatively similar. The economic analysis considers a common utility price across the board of $0.09 / kWh of electricity and $7.00 / GJ of natural gas (equal to $0.025 / ekWh). As a result, the multi-unit residential buildings with electrical baseboards have lower payback periods than similar buildings heated by natural gas. The payback years are almost irrelevant for market buildings that are only intended to meet the code minimums. When looking at solutions to meet code minimums, the only number that matters is the minimum cost for code compliance. For projects where compliance is demonstrated by energy modeling, the building envelope performance can be traded off against other energy efficiency measures that are typically more cost effective from a capital cost perspective. Nevertheless, the simple payback analysis provides a tool to rank different envelope scenarios.

Appendix E provides absolute energy savings for electricity and gas for each scenario in the cost-benefit analysis. These values can be used directly for any external economic analysis that considers different utility rates, either to account for geographic area or future utility rate forecasting.

The cost-benefit analysis presented in this guide provides a methodology to effectively quantify the energy savings and incremental costs associated with improving the thermal performance of the building envelope, including the impact of interface details. However, ASHRAE 90.1 and BC utility incentive programs also have their own detailed economic analysis. The raw data presented in this guide can be used in a more detailed economic analysis based on specific criteria, assumptions, and procedures required by these organizations.

For life cycle cost analysis, it should be noted that the expected service, maintenance requirements, and operation requirements can differ for building envelope components. However, as a general guideline, any component introduced into an assembly that is structural or not easily accessible should be designed to last the life of the building.

PART 3
SIGNIFICANCE, INSIGHTS AND NEXT STEPS

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3.1 OVERVIEW

With the abundance of information provided in Part 1 and 2, and related appendices, the question may arise “So what?” and “What do we do now?” Part 3 of this guide responds to these questions.

First in Section 3.2, Significance and Insights, the question of “So what?” is answered by highlighting the important stories and insights that follow from the analysis covered by this guide. Then the question of “What do we do now?” is covered in section 3.3, Next Steps.

Part 3 has insights and next steps for all the stakeholders. A focus of Part 3 is on market transformation, but there are also insights relevant to current design practice.

3.2 SIGNIFICANCE AND INSIGHTS

The significance of the body of work that supports this guide and insights are not simply summarized by mirroring Parts 1 and 2. Insights are presented by different viewpoints that are organized by high level themes. These themes present individual stories that are intended to create an informed impression without getting lost in the details.

Many of the themes presented below are suitable for future technical bulletins, which is discussed in section 3.3.

3.2.1 WOOD-FRAME BUILDINGS (TYPICALLY) HAVE BETTER BUILDING ENVELOPE THERMAL PERFORMANCE

With the spirit of “Wood First” in BC, the first theme to address is the ranking of wood-frame construction compared to other types of construction.

Wood-frame construction is inherently more thermally efficient due to the lower conductivity of wood compared to concrete, steel-frame, and masonry construction. As a result, the impact of thermal bridges caused by wood framing is less than materials typically used in non-combustible construction. The low conductivity of wood also makes it easier to account for thermal bridging in calculations because lateral heat flow is less of an issue and assumptions of parallel path heat flow are more valid for most wood-frame details. Moreover, since it is more easily determined, energy standards account for more thermal bridging in wood-frame construction than for other types of construction. For example, assumptions in ASHRAE 90.1, Appendix A, include extra framing such as plates, sills, and headers, for wood-framed walls. In contrast, steel framed walls do not account for any extra framing around openings. Nevertheless, not all thermal bridges

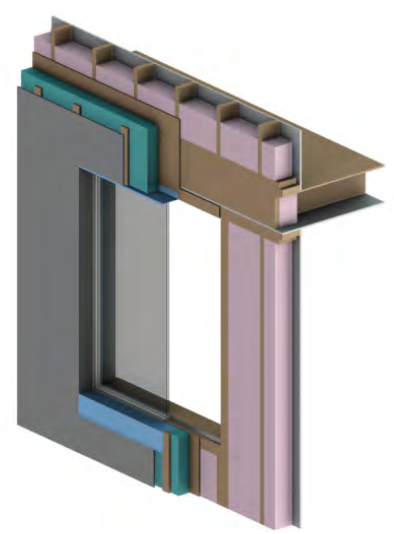


Figure 3.1: Wood-Frame Construction

are addressed. There can be a significant difference between the U-values assumed by ASHRAE 90.1, Appendix A and the overall U-value determined by the procedures put forward in Part 1 of this guide. Figure 3.2 compares the prescriptive requirements for thermal transmittance in the applicable BC energy codes and standards to the U-values contained in ASHRAE 90.1 Appendix A or by using the procedures outlined in Part 1 (BETA Calculation Method). The BETA values are part of the calculation for the Low-rise MURB scenarios contained in Appendix E.

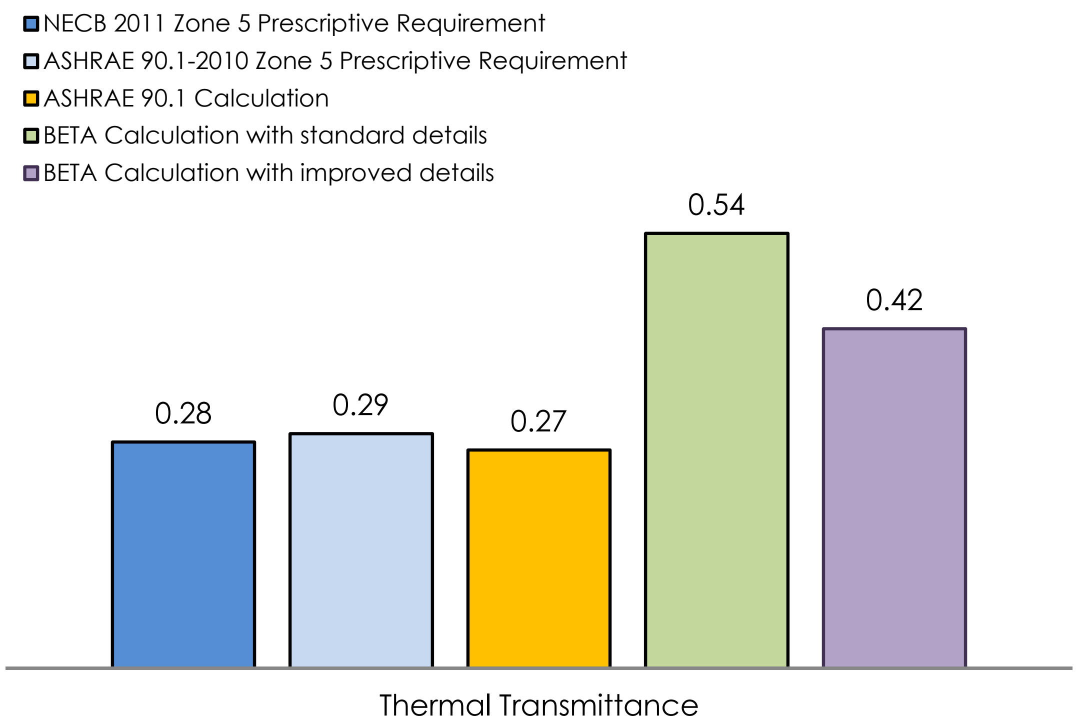


Figure 3.2: Comparison of the Thermal Transmittance (W/m²K) of ASHRAE 90.1 and BETA Calculation Methods for a Wood-Frame Wall Assembly with R-19 Batt Insulation in the Stud Cavity and R-5 Exterior Insulation

There are a limited number of wood-frame details covered by this guide, but generally the transmittances for the wood-frame details are low. Even the highest linear transmittance values for the wood-frame interface details with flashing are lower in comparison to similar details for other construction types. Nevertheless, the relative contribution of the interface details to the overall heat flow for wood-frame construction can add up to be more than the clear wall heat flow. This is largely because of how little heat flows through thermally efficient clear field wood-frame walls. For example, for a low-rise wood-frame building with 30% glazing, the contribution of the interface between an aluminum window and the adjacent wood framed wall ranged from 30% to 40% of the total heat flow through the opaque elements. The window interface contribution to the overall heat flow dropped by half with a vinyl window with similar positioning and detailing. Figure 3.3 compares wood-frame construction to steel-framed and concrete construction for regular details for the 30% glazing low-rise MURB building. The heat flow associated with the clear field assembly is broken out from the heat flow associated with the interface details to show the relative contribution to the effective thermal resistance for the different types of construction.

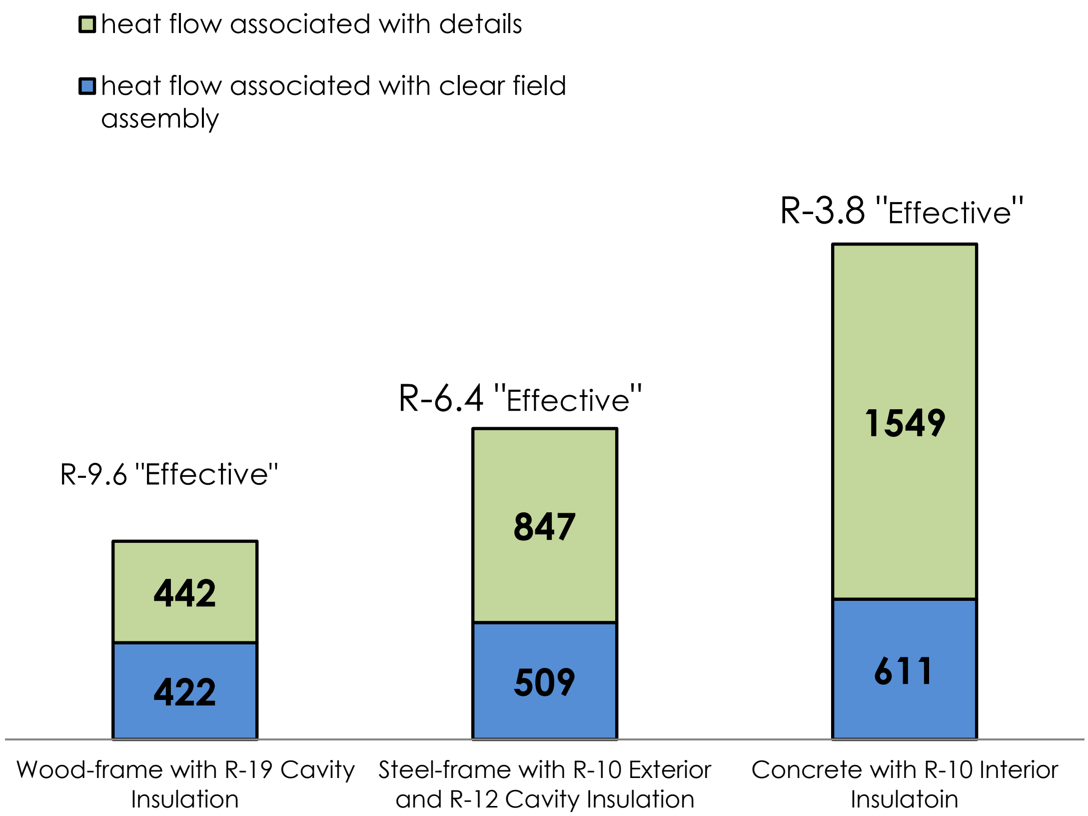


Figure 3.3: Comparison of Relative Contribution of Heat Flow (W/K) to the Effective Thermal Resistance (ºF ft2 hr/BTU) for Various Construction Types

Prescriptive requirements in energy codes and standards referenced by the BCBC for larger buildings (NECB 2011 and ASHRAE 90.1-2010) strongly encourage exterior insulation for wood-frame assemblies. As more insulation is added to the exterior of wood-frame walls, the improvement to energy savings become negligible due to the law of diminishing returns and the bypassing of insulation by thermal bridging. The impact of the heat flow at window interfaces can be significant, sometimes even exceeding the heat flow through the clear field of the well-insulated walls. Accordingly, improvements to the selection, design, and installation of windows for wood-frame construction will be increasingly more critical and cost effective than adding more exterior installation.

The impact of the interface details is not as dramatic for wood-frame construction and generally the energy use is less for buildings with wood-frame construction than for other types of construction. Nevertheless, other types of construction with exterior insulation and improved details can achieve the same over-all U-value as wood-framed construction. However, more attention is required to the details to achieve the same level of performance. For example, the cost benefit analysis in Appendix E shows how a low-rise MURB with a concrete structure and exterior insulated steel stud infill can meet the same U-value requirements as wood-frame construction, but requires thermally broken balconies and parapets and costs more (compare Case 1A to Case 2A of the Low-rise MURB with 30% glazing).

3.2.2 INTERFACE DETAILS ARE SIGNIFICANT IRRESPECTIVE OF CROSS SECTIONAL AREA

The cost-benefit analysis completed for this guide makes it clear that if reductions in energy use in our building stock is a real goal in society (and in codes) then thermal bridging at interface details cannot be ignored.

"For highly insulated walls, the U-values determined by the BETA method, with common details, is as high as **three to four** times the clear field U-value"

For larger buildings, there is currently a wide gap between the building envelope thermal performance that our energy code and standards assume and what is actually being built. Our analysis of archetype buildings, with concrete walls insulated on the inside with ASHRAE 90.1-2010 prescriptive insulation levels and common details, show the effective U value of the opaque walls are two to three times the prescriptive assembly U-value. The gap widens to as much as three to four times for wall assemblies that are insulated per NECB 2011 prescriptive levels.

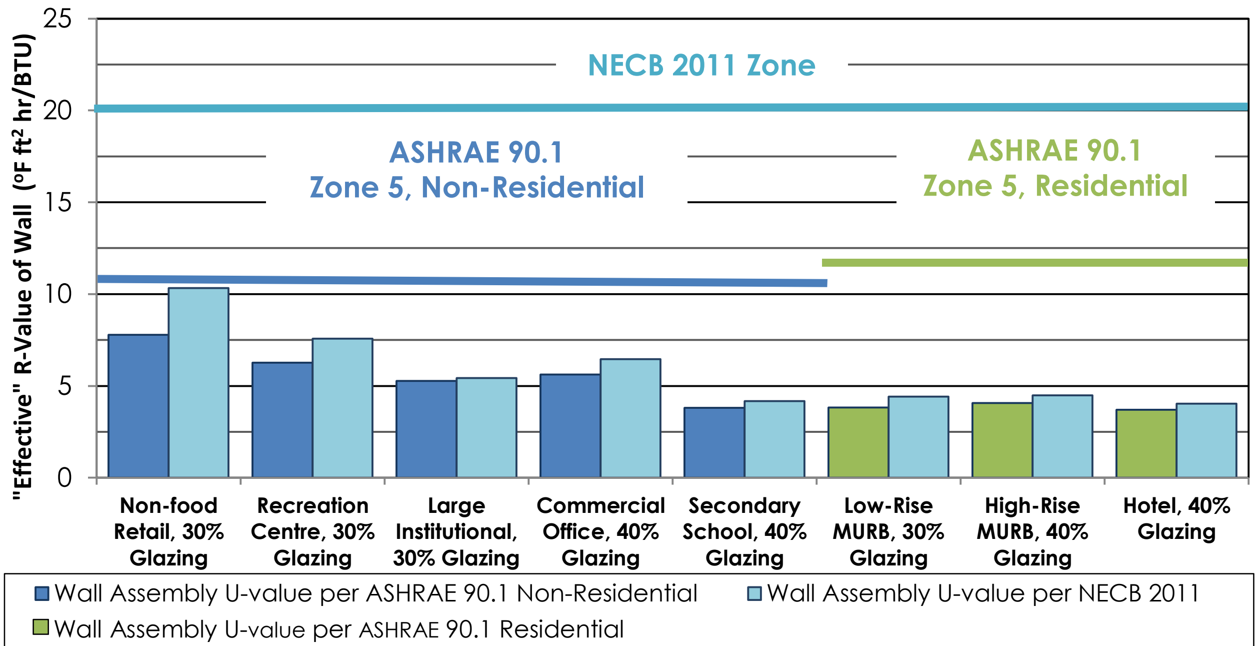


Figure 3.4: "Effective" R-value for the 30% to 40% Glazing Archetype Buildings with Concrete Walls and Common Details

For higher glazing ratios the gap between the assembly U-value and the overall U-value that includes interface details is higher, approximately 25% to 50% higher. This has implications for achieving code compliance using the performance path (i.e. whole building energy modeling) in energy codes and standards. Often the performance path is the desirable path for designers and developers looking to maximize the percentage of glazing. Clearly, with more glazing there will be more interface details per opaque area and the difference between the assembly U-value and U-value that includes details will be amplified. The following figure and table illustrates this concept for strip glazing, where the linear length of the glazing interface is constant. Note for punched windows, the linear length of the interface detail will increase with increasing glazing ratios and the difference will be larger.

40% Glazing **50% Glazing** **90% Glazing**

Table 3.1: Impact of Interface Details for Increasing Glazing Percentage

% Glazing	**Glazing Area** Conventional Curtain-wall with vertical mullions spaced at 5 feet (1.5 m) o.c.		**Opaque Area** Steel Stud Wall with Intermittent Clips spaced at 24 inch (610 mm), o.c. vertically and 16 inch (406 mm), o.c. horizontally		**% Reduction in "Effective" R-value**
	$U_{glazing}$ BTU/hr ft^2 ^{o}F (W/ m^2 K)	$R_{glazing}$ hr ft^2 ^{o}F/BTU (m^2 K/W)	U_{opaque} BTU/hr ft^2 ^{o}F (W/ m^2 K)	R_{opaque} hr ft^2 ^{o}F/BTU (m^2 K/W)	
40%	0.42 (2.36)	R-2.4 (0.42)	0.059 (0.34)	**R-16.8 (2.96)**	-
50%	0.42 (2.37)	R-2.4 (0.42)	0.061 (0.35)	**R-16.4 (2.89)**	2%
90%	0.39 (2.2)	R-2.6 (0.45)	0.101 (0.57)	**R-9.9 (1.74)**	41%

The archetype buildings are relatively simple in form, incorporating only a modest length of linear interface details. For more articulated architecture, interface details will have an even bigger impact (See section 3.2.3 for more discussion of the impact of articulated architecture).

It is clear that for future iterations of energy codes and standards requiring improvement of interface details will likely have a much more significant impact than requiring additional insulation. Moreover, improving interface details or devoting more attention to avoiding large thermal bridges is generally more cost effective than solely adding insulation. See section 3.2.4 for more discussion on the cost effectiveness of adding more insulation and the impact of mitigating thermal bridging combined with higher insulation levels.

The U-value gap due to interface details translates to as much as a 36 ekWh/m² difference in total annual energy. Tables 3.2 and 3.3 summarize the impact of interface details, in terms of annual energy use, for common concrete construction with either 30% or 40% glazing (Scenario 2, Case 1 in Appendix E). Note that 28% of the opaque area is glazing spandrel, in addition to concrete walls, for the commercial office building and 9% of the opaque area of the large institutional building is glazing spandrel.

Table 3.2: Comparison of Energy-Use related to ASHARE 90.1-2010, Zone 5, U-Values to BETA Method U-values for Common Concrete Construction

Building Type	ASHRAE 90.1-2010 Zone 5 U-Value W/m²K	BETA Calculation Value W/m²K	% Incr. U-Value	Total Energy Difference ekWh/m²	Energy Cost Difference $/m²
Commercial Office	0.51	0.97	91	8	$ 0.29
High-Rise MURB	0.45	1.39	210	11	$ 1.03
Hotel	0.45	1.54	242	20	$ 0.57
Large Institutional	0.51	1.10	115	16	$ 0.39
Low-Rise MURB	0.45	1.48	230	14	$ 1.24
Non-Food Retail	0.51	0.73	62	10	$ 0.30
Recreation Centre	0.51	0.91	77	6	$ 0.18
Secondary School	0.51	1.08	112	10	$ 0.34

Table 3.3: Comparison of Energy-Use related to NECB 2011, Zone 5, U-Values to BETA Method U-values for Common Concrete Construction

Building Type	NECB 2011 Zone 5 U-Value W/m²K	BETA Calculation Value W/m²K	% Incr. U-Value	Total Energy Difference ekWh/m²	Energy Cost Difference $/m²
Commercial Office	0.28	0.88	215	11	$ 0.41
High-Rise MURB	0.28	1.27	352	12	$ 1.08
Hotel	0.28	1.41	402	21	$ 0.62
Large Institutional	0.28	1.07	285	36	$ 1.20
Low-Rise MURB	0.28	1.29	359	13	$ 1.21
Non-Food Retail	0.28	0.55	96	12	$ 0.34
Recreation Centre	0.28	0.75	170	8	$ 0.35
Secondary School	0.28	1.36	389	14	$ 0.48

Moving beyond code compliance to voluntary ratings programs, such as LEED, developers and architects need to understand that there are different set of rules for modeling building envelope thermal performance than for simple code compliance. One difference is that interface details, such as projecting balconies, perimeter edges of intermediate floor slabs, concrete floor beams over parking garages and roof parapets, are often required to be accounted for in the proposed design building. Developers or building owners should expect that a competent energy modeler will account for these interface details for rating programs that follow these sets of rules. Moreover, if the building envelope design has major thermal bridges (i.e. cantilevered balcony floor slabs) it should be expected that this can be a major hurdle for getting energy related points for LEED or an equivalent program.

Meeting LEED requirements is even more difficult when you consider that energy “points” are achieved by comparing the energy use of the “proposed design building” to a baseline building that does not include an allowance for heat loss at interface details (i.e. the U-values are based on the prescriptive assembly maximum U-factors).

Figure 3.5: An example of thermal bridging at the interface between assemblies. This is NOT captured by wall schedules but reduces the insulation effectiveness

Good design considers the impact of interface details, not simply to comply with code, but because there is often additional advantages. Often (but not always) more thermally efficient building envelope details reduce the risk of condensation. Architects have a responsibility for coordinating the design team (i.e. mechanical designer, energy modeler, contractor) and that requires an awareness of the potential impact of design and construction of interface details.

With regard to accounting for the heat flow in the mechanical design, the buck stops with the mechanical designer. Good practice for load analysis requires a mechanical designer to accurately account for the heat loss through the envelope based on the architectural drawings. Gross assumptions or an inappropriate factor of safety can sometimes lead to operational inefficiencies related to under or over sizing of equipment. Good practice requires a quantity takeoff for each zone. An example of gross assumptions is reliance on a single U-value for the entire opaque building envelope based on wall schedules and ignoring the impact of interface details. This does not reflect the reality of construction. The good news is that this guide provides information to make detailed heat loss calculations easier for mechanical designers.

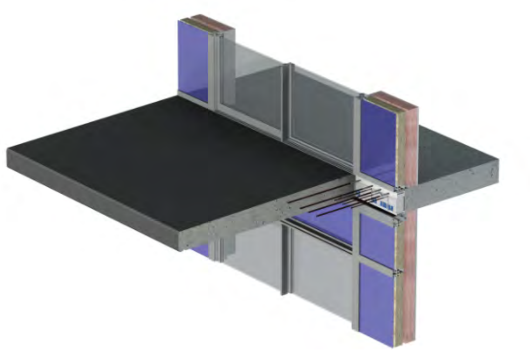


Figure 3.6: A thermally broken floor slab at a balcony and sliding door

An important consideration for everyone is that the cross sectional area is not a key indicator for evaluating the impact of thermal bridges. For example, steel studs have a small cross sectional area that bypasses any thermal insulation in the stud cavity and reduces the effectiveness of the insulation by 40% to 60% depending if there is exterior insulation and the stud spacing. There is well documented information to the expected performance of framed walls, and generally industry accepts that thermal bridging related to framing like studs must be considered.

For less frequent spaced thermal bridges, like balcony slabs or shelf angles, the impact is not often considered in practice. Justifications for this include that these penetrations are needed for structural purposes, the thermal impact is difficult to assess, they are a small proportion of the envelope area, or they can be considered negligible if the insulation is installed tight to the penetration (paraphrased from NECB 2011). The information in this guide should put these assumptions to rest.

The impact of these penetrations can be significant. For example, the high-rise multi-unit residential buildings covered by the cost benefit analysis included cantilevered balconies that are approximately 2.7% of the total opaque wall area. However, approximately 15% to 30% of the heat flow through the wall area is associated with the balconies. The relative impact depends on the efficiency of the wall assembly and other interface details.

"The cantilevered balconies are approximately 2.7% of the total opaque wall area but 15 to 30% of the heat flow through the opaque wall area is associated with the balconies"

For the high-rise MURB with 40% glazing with EIFS on concrete (Scenario 2, Base Case 2 in Appendix E), the heat flow associated with the balconies and exposed floor slabs accounted for approximately 40% of the heat flow. For the case with thermally broken balconies and improved EIFS details (Scenario 2, Case 2A in Appendix E), the heat flow dropped to only approximately 20% of the heat flow. The EIFS with improved details is a 59% improvement in U-value compared to the common interior insulated case (Scenario 2, Base Case 1 in Appendix E) and translates to 10 ekW/m^2 in electricity savings compared to the base case.

EIFS on concrete with improved details is an example where the U-value determined by the BETA method is close to the prescriptive requirements for Zone 5 of ASHRAE 90.1-2010. However, EIFS outboard of concrete, thermally broken balconies, and insulated parapets costs a lot more than what is currently common practice for interior insulated poured-in-place concrete walls.

These extra costs raise the question of what is an appropriate baseline for any economic analysis, which includes the impact of details that were previously overlooked. Some extra costs are expected to address thermal bridging at interface details compared to current practice. However, the magnitude of extra costs is debatable and depends on the reference point or how high the bar is set. If the bar stays set high (i.e. U-value requirements remain the same but interface details become part of U-value calculations) then some types of common construction, such as interior insulated poured-in-place architectural concrete, will be put under pressure from a cost perspective and alternative forms of construction will be much more attractive. If the bar is set low, reflective of what is currently built to meet code minimums, and then improving the building envelope by better details is very cost effective.

Regardless where the bar is set, improving interface details is likely to be more cost effective than adding more insulation or upgrading to triple glazing. Figure 3.7 illustrates the cost effectiveness of improving interface details for concrete framed construction with steel stud infill (Scenario 1, Case 1 in Appendix E) compared to adding more insulation and upgrading to triple glazing (Scenario 1, Case 4 in Appendix E) for the high-rise MURB with 40% glazing in Vancouver.

Where the bar should be set is an important consideration for energy code and standards when looking at addressing thermal bridging interfaces. More insights into the role of energy codes and standards can be found in section 3.2.6.

The question of what is an appropriate baseline is also an important consideration for utility incentive programs that require energy savings be demonstrated by energy modeling. These programs might set the bar low to reflect current practice and encourage better practice, then steadily raise the bar as thermal bridging is more effectively addressed in practice.

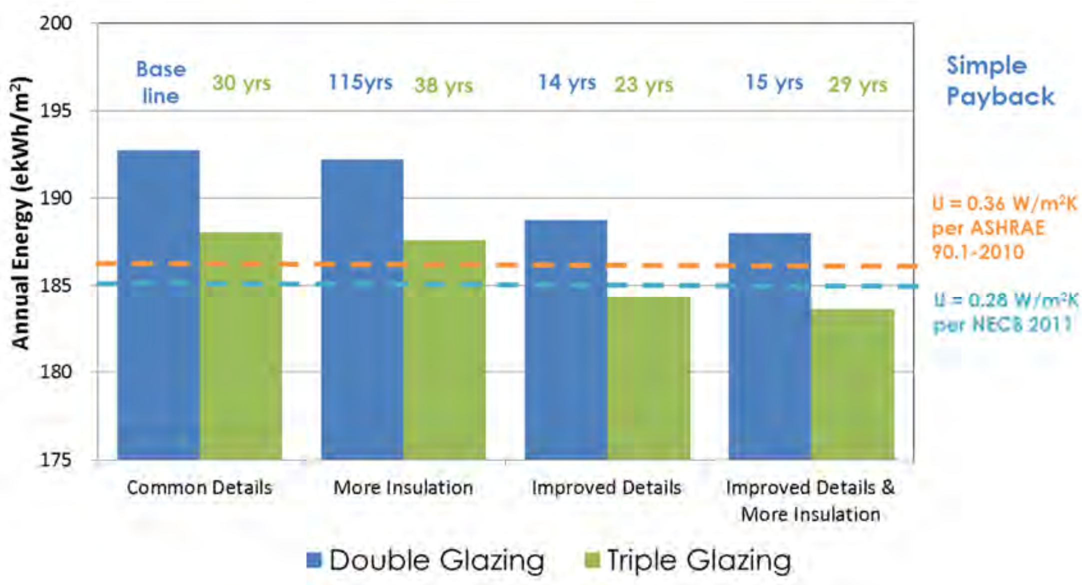


Figure 3.7: Comparison of Annual Energy Use and Simple Payback for High-Rise MURB with 40% Glazing in Vancouver

3.2.3 ARCHITECTURE

Design decisions made by architects can have a big impact on the overall building thermal performance. Decisions that lead to more interface details, will typically lead to additional heat flow. Examples include articulating architecture, glazing broken up by small areas of opaque walls, and glazing orientation. Some thermal bridges can be completely avoided or substantially decreased, such as concrete shear walls or eyebrows.

The quantity of interface details in the archetype buildings used for the cost-benefit analysis is modest compared to some new construction. A straightforward approach to encouraging less energy intensive design is to require that the energy impact of the interface details be included in U-factor calculations for code compliance and voluntary performance programs.

Figure 3.8: A common form for a residential tower in BC with many thermal bridges at interface details

For example, the impact of a concrete shear wall intersecting with interior insulated concrete walls between the units of a high-rise residential building was considered in the cost-benefit analysis (Scenario 2, Case 1B in Appendix E). Simply avoiding the concrete shear walls coming to the exterior, results in a 1.4 to 2.1 eKWh/m^2 in electrical savings, for all the climates.

Assembly selection far outweighs the costs related to mitigating thermal bridges at interface details. Some assemblies inherently have less thermal bridging at interface details. Therefore, it is rational to compare between competing assemblies. However, the incremental costs between competing assemblies overshadow even the most expensive upgrades to specific interface details.

Figure 3.9: A concrete shear wall bypasses the thermal insulation (seen from the interior). The blue material is insulation, is on both sides of the concrete wall. The concrete wall is part of the suite separation.

Table 3.4 demonstrates this concept by comparing the costs and performance of two exterior insulated steel stud assemblies, metal panel (Scenario 1, Case 1 in Appendix E) and EIFS (Scenario 1, Case 2 in Appendix E). The EIFS assembly has slightly better performance than the metal panel assembly for the same level of exterior insulation (R-15), but cost less. The difference in cost between the assemblies is far more than the cost to provide thermally broken balconies and parapets.

These decisions are not just made by architects; entire design teams and owners will need to get onboard to improve practice related to building envelope performance. This circles back to the importance of the codes and standards to set the bar so that industry is on a level playing field. More discussion about energy codes and standards related to encouraging improved designed practice is covered in section 3.2.6.

Table 3.4: Cost and Performance Comparison of Two Types of Steel Stud Assemblies

Type of Steel Stud Wall Assembly	Interface Detail Scenario	U-Value (W/m^2K)	Incremental Costs	Energy Cost Savings	Payback
Metal Panel	Common	0.95	-	-	-
	Improved	0.60	$149,394	$10,019	14
EIFS	Common	0.92	$(2,136,608)	$965	0
	Improved	0.51	$ (1,692,257)	$11,489	0

3.2.4 The Effectiveness of Adding More Insulation

Analysis summarized in Appendix E shows that adding more insulation to already highly insulated wall assemblies, with common interface details, has little impact on building energy use. This is true for wood-frame and non-combustible construction. Adding more insulation to wall assemblies has diminishing returns regardless of the interface details, but these diminishing returns are amplified by the presence of significant thermal bridges.

The payback for adding more insulation to assemblies that are already highly insulated is high, because of the minimal reduction in energy use. This is true even if the impact of the details are not considered. Table 3.5 summarizes the payback for exterior insulated steel stud assemblies with metal panel with an “effective” R-value of R-15.6 (ASHRAE 90.1-2010 prescriptive requirement for Zone 5) compared to R-20 (NECB 2011 prescriptive requirement for Zone 5) for the buildings with 30% or 40% glazing (Scenario 1 of Appendix E). The construction costs and energy savings presented in table 3.5 do not consider thermal bridging at interface details.

Table 3.5: Cost and Performance Comparison of Adding More Insulation to Steel Stud Assemblies to go from an “Effective” R-value of R-15.6 to R-20

Building Type	Incremental Construction Cost	Energy Cost Savings	Payback (years)
Commercial Office	$ 94,825	$ 1,116	85
High-Rise MURB	$ 153,222	$ 2,542	60
Hotel	$ 64,650	$ 543	119
Large Institutional	$ 150,375	$ 1,833	82
Non-Food Retail	$ 24,192	$ 461	53
Recreation Centre	$ 28,400	$ 263	108
Secondary School	$ 36,325	$ 306	119

The costs for adding more insulation is quite high when compared to the energy savings.

Simple no cost changes, such as avoiding bringing shear walls to the exterior walls of interior insulated concrete walls (Scenario 2, Case 1B for High-Rise MURBS in Appendix E), can achieve energy savings of a similar magnitude as to adding insulation.

Even some “expensive” options look attractive when compared to the cost effectiveness of added insulation. The cost to upgrade to thermally broken balconies and parapets for the high-rise MURB with 40% glazing (Scenario 1, Case 1 in Appendix E) may be three times the cost of increasing the effective wall assembly R-value from R-15.6 to R-20. The resultant savings, however, is more than seven times as much. Better details AND adding insulation translates to the most energy savings and the best payback period.

Adding insulation to interior insulated concrete assemblies (Scenario 2 in Appendix E) did show paybacks that were 30% - 40% lower than the above example with exterior insulated steel stud walls, but only if you assumed that there are no extra costs associated with thicker walls. If there are costs associated with thicker walls, due to FSR constraints, then adding insulation to interior insulated walls would be very expensive.

The implication highlighted by these examples is that increasing insulation requirements to assemblies without considering the impact of interface details will in some cases cost industry more money but will not result in any significant energy savings. Conversely, adding more insulation and improving details can result in real energy savings.

Notwithstanding the general message that paying attention to interface details pays off more than adding insulation, more insulation is sometimes a good solution. For example, adding insulation outboard the metal framing of glazing spandrel sections can result in appreciable reductions in U-value and energy use. Glazing spandrel performance can be improved by incorporating vacuum insulation panels into double glazed sealed units (referred to as AIM or Architectural Insulated Modules in the thermal performance catalogue) or adding spray-foam behind the metal back pan. Improving glazing spandrel sections is discussed under new and innovative technologies in section 3.2.8.

3.2.5 Ranking of Opaque and Glazing Thermal Performance

Regulators and designers are starting to realize that they need to focus on improving glazing performance because glazing U-values are assumed to be so much higher than what is assumed will be provided by the opaque building envelope. Unfortunately, analysis in Appendix E shows that when interface details are taken into account, the overall U-value of the opaque building envelope may not be that much higher than the vision areas. Also, the opaque areas do not have the potential of providing solar heat gain in the winter or daylighting. Upgrading windows may be important but not at the expense of ignoring the performance of opaque elements.

Cases with triple glazing were evaluated for the commercial and the high-rise multi-unit residential buildings to benchmark the cost effectiveness and energy savings of the opaque building envelope (Case 2 for Commercial and Case 4 for High-rise MURB in Appendix E). The triple glazing scenarios resulted in some of the lowest energy use, but the same savings could be achieved by modifications to the opaque elements. For example, the multi-unit residential building with 40% glazing, the case with EIFS and thermally broken balconies has more energy savings than triple glazing with standard details.

Table 3.6: Cost and Performance Comparison of Opaque Building Envelope to Triple Glazing for High-Rise MURB with 40% Glazing

Wall Assembly	Glazing Assembly	Interface Detail Scenario	U-Value (W/m^{2}K)	Incremental Costs	Energy Cost Savings	Pay Back
Baseline: R-10 Exterior and R-12 Interior Insulated Steel Stud Assembly	Double Glazing	Common	0.95	-	-	-
R-7.6 EIFS and R-12 Interior Insulated Steel Stud Assembly	Double Glazing	Common	0.92	$(2,136,608)	$965	0
R-15 EIFS Steel Stud Assembly	Double Glazing	Improved	0.51	$(1,692,257)	$11,489	0
R-10 Exterior and R-12 Interior Insulated Steel Stud Assembly	Triple Glazing	Common	0.95	$346,125	$11,678	30
R-15 Exterior Insulated Steel Stud Assembly	Triple Glazing	Improved	0.60	$496,995	$21,053	23

From a payback perspective, the triple glazing scenarios are generally on par with the "more insulation" cases. However, the triple glazing scenarios are amongst the most expensive cases. Regulations in BC are trending towards more expensive glazing systems to reduce energy use in buildings. The fact that there are opaque envelope solutions that provide similar gains in terms of reducing energy consumption, but cost less, should provide more incentive for codes to address thermal bridging at interface details. Addressing the interface details and improving the glazing together have the potential to make the biggest reductions in energy use.

3.2.6 The Role of Energy Codes and Standards

This guide places a lot of attention on how market buildings are affected by codes and standards, because the simple action of requiring consideration of thermal bridging at interface details will be the catalyst for market transformation.

A more holistic attitude to evaluating the impact of thermal bridging, as outlined by this guide, is needed for assessing the economics of current insulation requirements and methods. The cost-benefit analysis underlined the significance of interface details and that past economic analysis based on assembly insulation levels are likely not completely valid.

This guide highlights that there are many approaches to reducing energy through improvements to the building envelope performance. These improvements have a wide range of associated costs. Once designers are forced by code to consider the impact of interface details then thermal bridging will simply become another factor that must be considered to comply with code.

The market will gravitate to the optimum and most cost effective solutions, because there are not a lot of opportunities to market the attractiveness of thermally efficient details. Architecture and assembly selection have far more impact on costs than even the most expensive detail improvements. Furthermore, changes to the code to address thermal bridging at interface details will likely make technology-driven improvements more cost effective because new technologies will become common as industry is expected to respond with more innovation.

We first need to move past the idea that the only thing a designer or authority having jurisdiction needs to think and check is how much insulation is provided, if consistent outcomes will be realized for large buildings. This is largely an issue with ASHRAE 90.-2010 and not NECB 2011. NECB 2011 has already moved beyond this line of thinking and is based exclusively on effective U-values. Even if "continuous" insulation, (i.e. insulation that is only interrupted by service openings) existed in practice, such as EIFS without flashing, then parapets and balcony slabs would have to be wrapped with insulation. This is possible for exterior insulated steel stud assemblies, but this is not reality for interior insulated poured-in-place architectural concrete walls that are ubiquitous in BC construction. This is not a reality because floor slabs bypass the thermal insulation for this type of construction, and actual continuous insulation cannot be achieved. Despite the intent of the continuous insulation concept, to make it simple and not require calculations, this approach has created confusion in industry and enforcement challenges.

When heat transfer at interface details become part of the equation, for U-value calculations in energy codes and standards, then U-value requirements might need to be relaxed for the interim. The justification would be an acknowledgement that a gap exists between the clear field or assembly U-values and the reality of what is achieved in practice when interface details become part of the equation. The BETA approach makes it straightforward to set baselines based on any assumed common detail or target performance level. Moreover, getting industry to accept the concept of the BETA approach might be easy in comparison to making the changes to energy codes and standards. Reaching acceptance of the finer details and assumptions will take some work, but with some optimism, the methodology and data presented in this guide will lead the way to constructive changes.

3.2.7 Tackling Thermal Bridging at Window Transitions

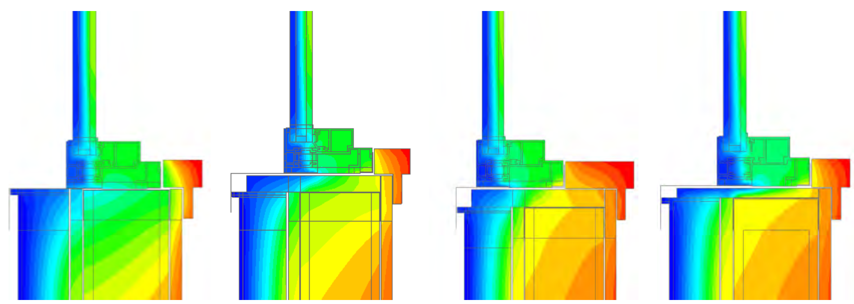
The work covered by Parts1 and 2 of this guide underscored the significant impact that thermal bridging at glazing interfaces can have on overall U-values and energy consumption.

Appendices A and B only scratch the surface to the amount of work and attention that is warranted for this subject given the significance, range of different window and wall construction, and possible improvements. More analysis is warranted on the impact of thermally efficient flashing, placement of windows, bringing insulation into window openings, and alignment of insulation.

ISO 14683-2007 provides broad order of magnitude assumptions for linear transmittance values of window and door openings for:

- Different placement of windows and discontinuous thermal insulation at openings
- Bringing the thermal insulation into openings
- Large conductive paths around the perimeter of openings.

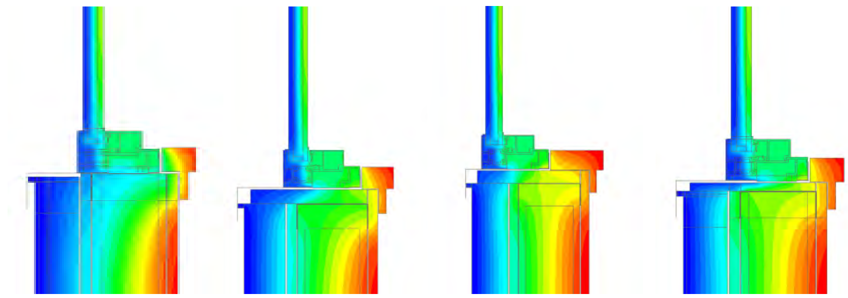
However, these values do not account for the complex heat flow resulting from flashings, thermal breaks from wood liners, different window types (frame material, spacer and thermal break), the interface of the window with framing of the wall assembly, and placement of windows in relation to the thermal insulation. Small differences can impact the heat flow, and consequently linear transmittance, which can be significant for the quantity of window glazing interfaces there are for buildings. This complex interaction is not only relevant to heat loss, but also is an important consideration for evaluating the risk of condensation. The following example highlights the relative impact of introducing a wood liner, moving the window position, and insulating the window opening for an aluminum framed window in a punched steel stud opening with exterior insulation. For this analysis, only the sill was considered.



	Base Case	**Plywood Liner**	**Plywood Liner with Window at Exterior**	**R-4 Insulation Wrapped into Opening**
Linear Transmittance (W/m K)	0.41	0.24	0.21	0.21
Glass Temperature Index at Edge (-)	0.465	0.464	0.460	0.456
Frame Temperature Index (-)	0.503	0.505	0.499	0.485

A difference in linear transmittance between the base case and R-4 wrapped into the opening has notable impact on energy consumption. For example, when comparing the base case to the R-4 insulation wrapped into the opening, **for the entire window interface**, the linear transmittances are 0.32 and 0.19 respectively. For the high-rise MURB with 40% glazing for the EIFS with improved details scenario (Scenario 1, Case 2A in Appendix E), the difference between these two interface details translates to an "Effective" R-value of 9 versus 11 and a difference in electricity energy savings of approximately $2,900. This amount of energy savings is more than the difference between the base case with common details, U-value of 0.35 W/m^{2}K (ASHRAE 90.1-2010 prescriptive requirement for zone 5) and an assembly with an additional R-10 exterior insulation or U-value of 0.28 W/m^{2}K (NECB 2011 prescriptive requirement for zone 5).

Interestingly, the linear transmittances for the same interface details, but with R-12 batt insulation in the stud cavity, are less. The difference is explained by the fact that the insulation in the stud cavity provides resistance to heat flow short circuiting the window thermal break for poorly positioned windows. Nevertheless, significant improvements can still be made for split insulated assemblies as summarized below.



	Base Case	Plywood Liner	Plywood Liner with Window at Exterior	R-4 Insulation Wrapped into Opening
Linear Transmittance (W/m K)	0.23	0.11	0.10	0.09
Glass Temperature Index at Edge (-)	0.465	0.457	0.456	0.453
Frame Temperature Index (-)	0.503	0.492	0.491	0.490

3.2.8 NEW AND INNOVATIVE TECHNOLOGIES

This guide includes a few new emerging technologies and applications that have been recently evaluated for manufacturers. These include:

- Vacuum insulated panels (VIP) in insulated glazed units for glazing spandrel sections called Architectural Insulated Module (AIM) manufactured by Dow Corning. AIM applications included spandrel sections for window-wall, conventional curtain-wall, high performance curtain-wall, and unitized curtain-wall.
- Structural thermal breaks manufactured by Schöck for several applications, including cantilevered concrete balconies, concrete parapets, interior insulated poured-in-place concrete walls, concrete to steel connections (like balconies), and steel to steel beam penetrations.
- Cladding attachments incorporating thermal breaks and innovative materials for various manufacturers.

The following sections discuss the significance of these technologies.

3.2.8.1 Evaluating and Improving Glazing Spandrel Sections

Spandrel sections are common in BC construction for window-wall and curtain-wall. There are two questions that industry is faced with:

1. What is the real performance of spandrel sections that fully accounts for lateral heat flow?
2. How can we improve the performance of spandrel sections?

Industry is increasingly recognizing that the performance of glazing spandrel sections is not adequately addressed by standard industry calculation methods. Two-dimensional procedures for determining the thermal transmittance of vision areas are not adequate for spandrel sections due to the much larger and variable edge effects. With a lot of work, better estimates of glazing spandrel sections can be found using two-dimensional computer modeling. Three-dimensional modeling overcomes this hurdle. This guide covers benchmarks for what should be expected for glazing spandrel sections for generic sections. Nevertheless, a lot of work can still be done for cataloguing the performance for generic systems and components.

This guide has made significant strides with regards to evaluating solutions to improve spandrel sections. One of these solutions is the inclusion of AIM in spandrel sections.

The costs associated with spandrel sections with AIM spandrel sections are similar to adding medium density spray applied polyurethane foam (spray foam) inboard of the metal back pan of spandrel sections. However, the costs provided by the general contractor for this guide for adding spray foam inboard the back pan of conventional curtain-wall appear to be on the high side, thus making the AIM spandrel sections appear very cost effective.

Regardless of the real costs that will be realized on a project, the AIM spandrel panels have similar improvements to performance as adding spray foam inboard of the metal back pan. However, AIM has some additional benefits that were not likely fully captured by the construction cost estimates that include:

- Easier sequencing and less construction time than insulating after the curtain-wall is installed (unitized approach).
- Potential architectural benefits and cost savings of not needing to finish inboard of the spandrel section.

The construction cost estimates also likely did not include any special measures for fire protection other than typical drywall. Combining AIM with four sided unitized curtain-wall and triple glazing vision sections for the commercial building with 70% glazing resulted in 21 to 33 ekWh/m^2 gas savings and payback of 23 to 44 years, depending on climate, compared to commonly insulated unitized curtain-wall spandrel sections (Scenario 1, Case 2 in Appendix E). This payback is reasonable considering the current low price of natural gas in BC ($7/GJ or $0.025/ekWh). Tables 3.7 and 3.8 show the U-value reduction and payback for upgrading from double glazing to triple glazing for base assemblies compared to AIM applications.

Table 3.7: Opaque U-values and Incremental Construction Costs for an Office Building with 70% Glazing and Unitized Curtain-wall with and without AIM

Assembly Scenario	Interface Detail Scenario	Glazing	Opaque U-Value BTU/hr ft^2 ^{o}F (W/m^{2}K)	% Reduction in U-Value	Incremental Construction Costs
Base Assemblies	Common	Double	0.259 (1.47)	-	-
	Common	Triple	0.224 (1.36)	7%	$333,366
AIM Applications	Common	Double	0.125 (0.71)	52%	$149,104
	Common	Triple	0.095 (0.54)	63%	$482,622
	Improved	Triple	0.092 (0.52)	65%	$496,473

Table 3.8: Energy Savings and Payback for an Office Building with 70% Glazing and Unitized Curtain-wall with and without AIM

Assembly Scenario	Interface Detail Scenario	Glazing	Lower Mainland (Zone 5C, Cool-Marine)		Okanagan (Zone 5B, Cool-Dry)		Prince George (Zone 7, Very Cold)	
			Energy Cost Savings	Pay Back	Energy Cost Savings	Pay Back	Energy Cost Savings	Pay Back
Base Assemblies	Common	Double	-	-	-	-	-	-
	Common	Triple	$6,619	50	$7,462	45	$10,870	31
AIM Applications	Common	Double	$5,904	25	$5,779	26	$6,542	23
	Common	Triple	$11,205	43	$12,745	38	$17,566	27
	Improved	Triple	$11,362	44	$12,930	38	$17,787	28

From these tables it can be seen that for this case, using AIM results in a shorter payback period than simply upgrading to triple glazing and can significantly decrease the U-values for the curtain-wall system. This showcases the potential to reduce heating energy significantly below the code minimum while still having high percentage glazing.

Even in buildings with lower glazing percentages and less curtain-wall, these types of AIM systems will have more of an impact compared to simply adding more cavity insulation. Figure 3.12 shows the relative paybacks for a variety of scenarios for a commercial building with 40% glazing.

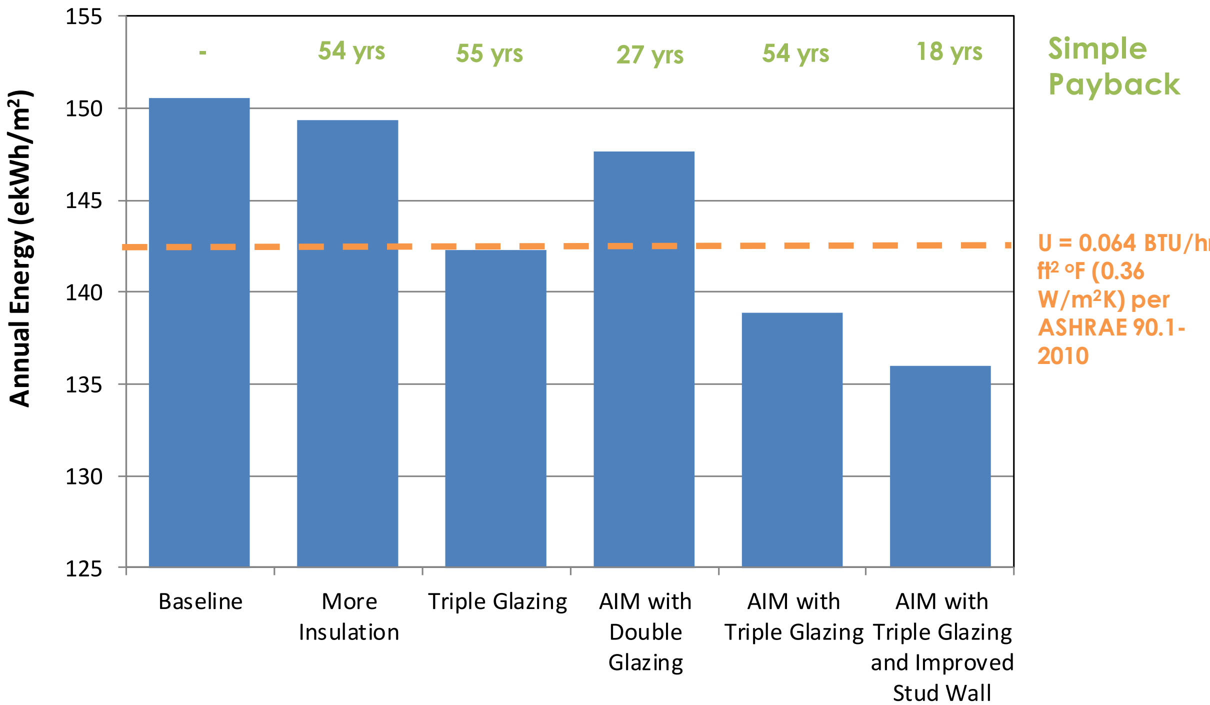


Figure 3.10: Energy Consumption and Payback for AIM Applications to other Envelope Improvements for the Commercial Building with 40% Glazing

3.2.8.2 Manufactured Structural Thermal Breaks

As outlined in section 2.3, new technologies from Schöck appear to be priced at a premium. These products address thermal bridging at details that have not been a concern in the past, which come at a cost. However, these manufactured solutions are not that costly compared to wrapping continuous insulation around parapets and balconies like some suggest is required to meet prescriptive requirements in ASHRAE 90.1. Moreover, these products combined with efficient wall assemblies have the potential for real energy savings.

From a cost perspective, you can look at these new technologies from two quite different perspectives.

1. Assume what we are doing is now is acceptable. Compare the cost of manufactured structural thermal breaks to common practice where unmitigated and overlooked thermal bridges are the norm.

2. Assume what we are doing now is not acceptable, we need to account for these significant thermal bridges, and compare to alternatives.

If you look at structural thermal breaks compared to what we are doing now, then the payback period is significant, but the energy savings are real. In comparison to adding more insulation, the payback is still less and the energy savings are considerably more. Therefore from a code perspective and consumer benefit, there is an economic argument for introducing changes that prescribe, or at least assume, thermally broken parapets and balconies in baseline buildings for performance paths to demonstrate code compliance.

Structural thermal breaks are also more cost effective than alternatives such as wrapping insulation around parapets and balconies. Despite manufactured thermal breaks not being free of thermal bridging, these technologies are more effective in reducing thermal bridging than wrapping parapets or balconies.

For example, the heat loss is reduced by more than 85% compared to common practice for the thermally broken parapet (Detail 5.5.12 in Appendix A) compared to approximately 60% reduction for wrapping insulation around the parapet (Detail 5.5.4 in Appendix A). The parapet with wrapped insulation does not deal with the geometric thermal bridge, additional heat flow due to geometry, which is a result of heat flowing to the parapet and the increased surface area exposed to the exterior. The following graphics illustrate the difference between a thermally broken concrete parapet and a fully insulated parapet. Note the clear wall assemblies are slightly different, but the insulation levels are identical and the clear field thermal transmittances are essentially the same.

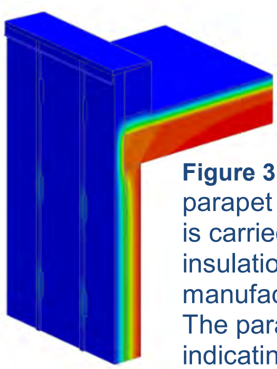


Figure 3.11: A thermally broken parapet where the roof insulation is carried to the exterior insulation at the same level via a manufactured thermal break. The parapet is cold (blue), indicating less heat flow and a more efficient system.

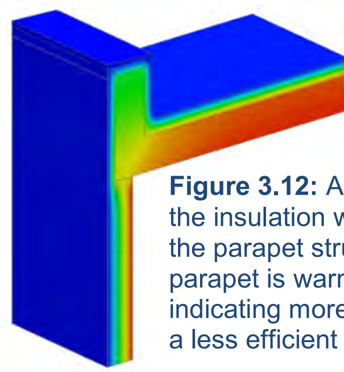


Figure 3.12: A parapet with the insulation wrapped around the parapet structure. The parapet is warm (green), indicating more heat flow and a less efficient system.

This example highlights a scenario where a new and innovative technology is more cost effective than the prescriptive requirements that energy standards might adopt if thermal bridging will be thoroughly addressed. If energy standards assume insulation wrapped around a parapet as the baseline, then there will be a significant incentive for designers to consider cost effective solutions such as structural thermally broken parapets.

3.2.8.3 Cladding Attachments

Many new methods for the structural attachment of claddings have been recently developed in response to code changes in BC and Ontario after more stringent energy standards were adopted. These innovations highlight the ability of the construction industry to effectively respond to more stringent energy standards and innovate.

Thermally efficient methods for attaching claddings make fully exterior insulated steel stud wall assemblies with high levels of effective thermal resistance more cost effective. Moreover, designers now have better options to provide high levels of effective thermal resistance without introducing additional risk, from a moisture management perspective, by adding additional insulation to the stud cavity.

Thermal performance data for many proprietary systems for the structural attachment of claddings are presented alongside generic systems in Appendices A and B of this guide. This information provides the foundation and opportunity for designers to develop performance based specifications for projects.

Structural analysis, thermal analysis and feedback from installers of these systems provide some reasons why project specific performance specifications should be considered:

- Every system will have different maximum spacing of structural members for a given design wind load. The spacing for these systems is often a function of the stiffness of the outer girt, the capacity of structural members, and the method of fastening members together and to the wall.
- The thermal performance of a wall assembly is affected by the spacing, or grid pattern, of structural members that go through the thermal insulation.
- Specifications can be set by the expected structural and thermal performance.
- Installers want a system that is adjustable at the rain-screen cavity. Sub-trades might charge a premium or resist a system that is unforgiving and difficult to install.

Figure 3.16 shows the effective thermal resistance for an exterior insulated steel stud assembly (with no cavity insulation) with various intermittent cladding attachments. The structural members penetrating the thermal insulation are attached to steel studs spaced at 16 inch o.c. and are spaced vertically at 24 inch o.c. Figure 3.15 illustrates the generic horizontal steel clip and sub-girt scenario. The other cladding structural attachments outlined in figure 3.16 are variations of this wall assembly. Detailed information about the specific components for each type of structural attachment can be found in section 5 of Appendix A.

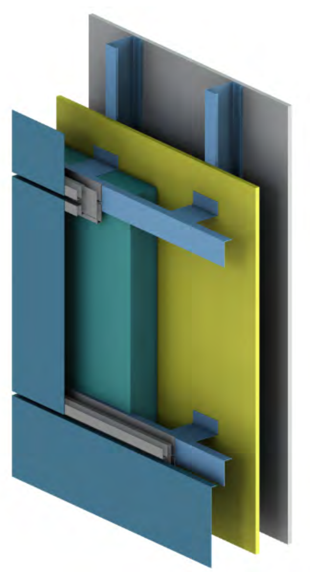


Figure 3.13: Exterior Insulated Steel Stud Assembly with the Generic Horizontal Steel Clip and Sub-girt

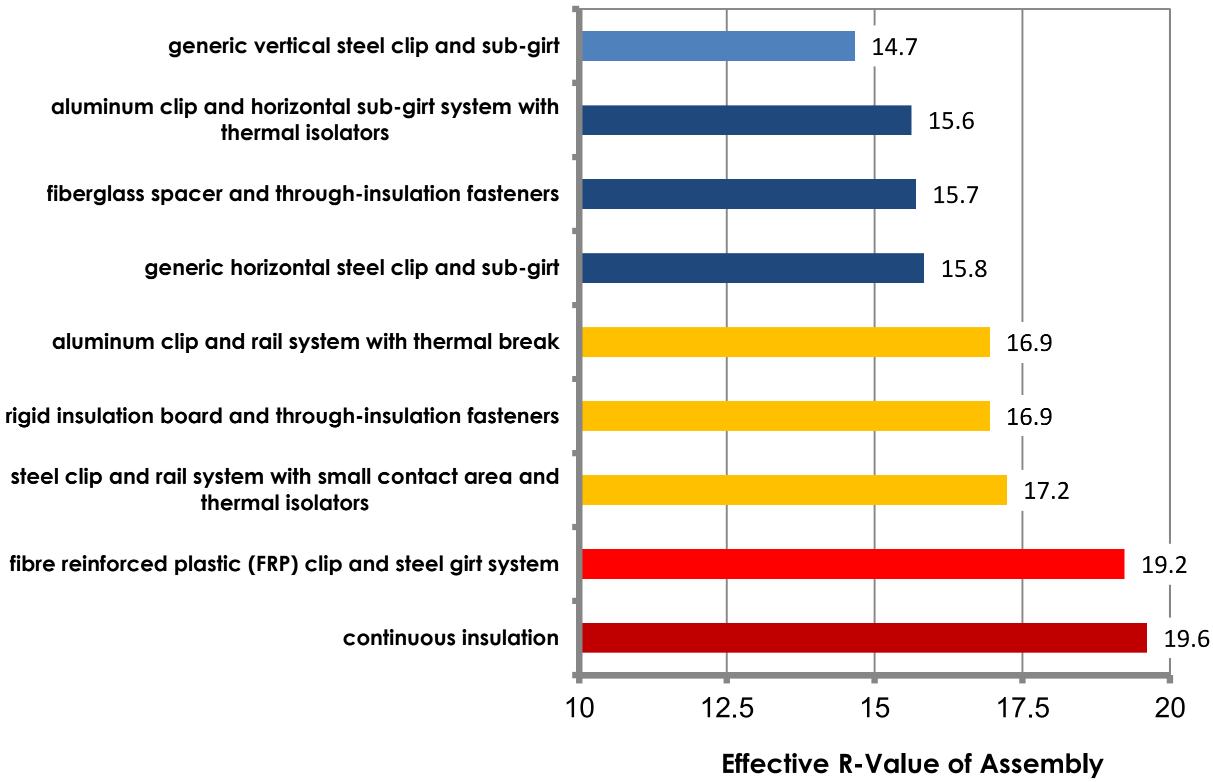


Figure 3.14: Comparison of Various Intermittent Attachment Methods for R-16.8 Exterior Insulation with the Attachment Member at 24 inches o.c. Vertically and 16 inches o.c. Horizontally

An important takeaway from figure 3.16 is that the differences between the systems cannot be explained solely by the material conductivity and cross sectional area of the members penetrating the insulation. These systems have complex heat flow paths. Thermal performance is also impacted by the contact area between components, the type and location of thermal breaks and isolators, and how far the structural components penetrate the thermal insulation. As a result, prescribing acceptable alternatives based on broad characteristics, such as cross sectional area, could be problematic if there is little acceptance, from designers, for variances in the thermal performance of installed walls.

Performance specifications based on the required U-value for the structural design loads of a project provide flexibility to sub-contractors to choose the system that is most cost effective to them, while ensuring that the thermal performance expectations will be met. Both the thermal and structural performance should be considered concurrently for design specifications because the grid pattern of structural members can have a big impact on the thermal performance. Figure 3.17 compares the effective thermal resistance of the structural attachments at a vertical spacing at 24 inch o.c. and at the spacing of the structural attachments that is required for a common wind load of 40 psf. Often a vertical spacing of 24 inches o.c. is reported and used to compare the thermal performance of various intermittent structural attachments for cladding. However, the thermal performance of some proprietary systems might appear to be more thermally efficient than others if the structural performance is not factored into decision making, but are not better in reality if project specific design loads are considered. In some cases, the installed wall assembly might even fall well below expectations.

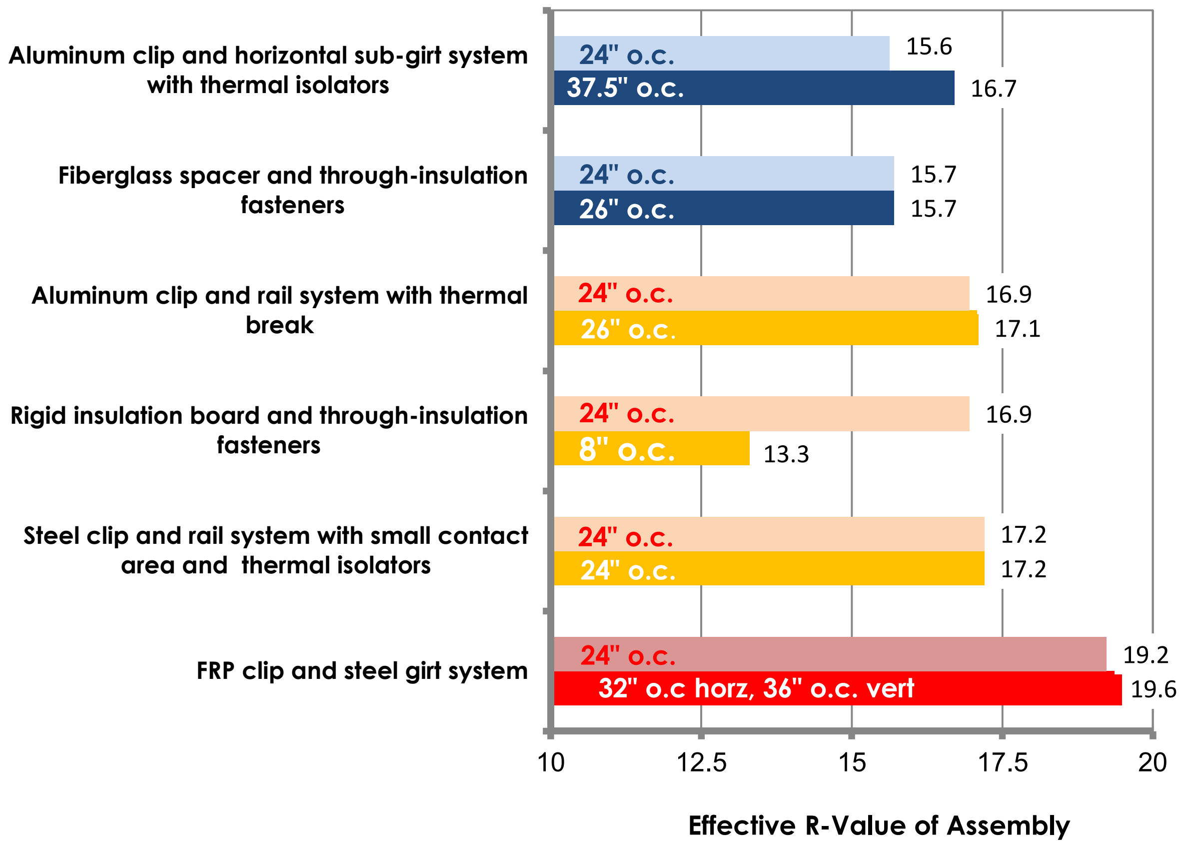


Figure 3.15: Comparison of Various Intermittent Attachment Methods with Attachment Members Spaced per the Structural Requirements Based on a Design Wind Load of 40 PSF[1]

3.2.9 Exterior Insulation Finish Systems (EIFS)

In the past, EIFS was more commonly installed in BC because this type of system is inexpensive and provides thermally efficient wall assemblies; however, it has fallen out of favour in the past two decades. EIFS systems have evolved since then to be more durable yet still offer a cost effective and thermally efficient alternative to other types of claddings. In many respects, EIFS is the only wall assembly that is close to the notion of continuous insulation many in the building industry believe is important. However, even though it is often referred to as a “continuous insulation” system, EIFS systems are not immune to thermal bridging at interface details, such as misaligned windows discussed in section 3.2.7.

For poured-in-place concrete construction, EIFS can significantly improve performance compared to interior insulation. Reiterating from section 3.2.2, a savings of 10 ekW/m^2 in electricity energy was determined for the high-rise MURB with 40% glazing with EIFS on concrete and thermally broken balconies compared to common construction

[1] Based on the design guides provided by manufacturers for proprietary systems or fasteners for rigid insulation board and through-insulation fasteners (NTA engineering evaluation report: TRU 110910-21). Lightweight cladding (5 psf) and 18 guage steel studs was assumed in this analysis.

(Scenario 2, Case 2A in Appendix E). However, there is currently no immediate incentive to realize these savings during design because continuous insulation is installed inboard of poured-in-place concrete walls and are deemed to comply with code. Installing insulation inboard of the concrete is made ineffective because it is bypassed by concrete floor slabs. This highlights the need for industry to move past the idea that a designer or authority having jurisdiction only needs to determine how much insulation is required, if real energy savings through improved the building envelope thermal performance is to be realized. This is largely an issue with ASHRAE 90.1 -2010 and not NECB 2011. NECB 2011 has already moved beyond this line of thinking and is based exclusively on effective U-values.

In terms of the thermal performance of EIFS details and common construction, Figure 3.18 illustrates the gap between standard concrete constructions with interior insulation to EIFS on concrete for all the 30% to 40% glazing archetype buildings. While the difference is significant, there is still room for improvement. The increase in energy savings mainly comes from the ability of EIFS to cover the exposed slab edges, while interior insulated concrete systems do not. However, both systems are still greatly affected by exposed balconies that, in this analysis, do not include synergies from using thermally broken balconies. This example also did not include other improvements at the parapet, window transitions, and spandrel sections and at-grade transitions.

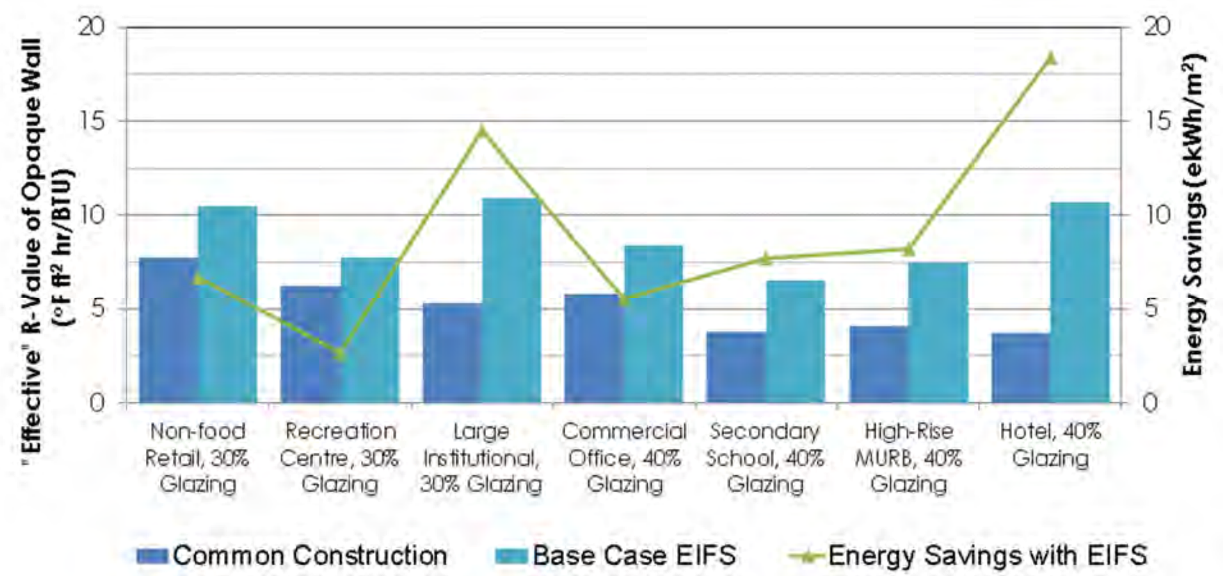


Figure 3.16: Comparison of Poured-in-place Concrete Walls with "Continuous" Insulation to the Base Case EIFS Wall Assemblies for all the Archetype Buildings for Vancouver (Except Low-Rise MURB)

In comparison to exterior insulated steel assemblies, illustrated in figure 3.19, EIFS does not have a significant advantage in terms of thermal performance and energy savings because large thermal bridges can be insulated with any exterior insulated assembly. The advantage comes more from the construction costs savings with EIFS compared to exterior insulated assemblies with cladding. Therefore, the costs to improve the overall performance, such as addressing balconies and spandrel sections, can be more than offset by the savings related to a cost effective assembly such as EIFS. Again, other improvements are still possible that were not considered in this particular analysis.

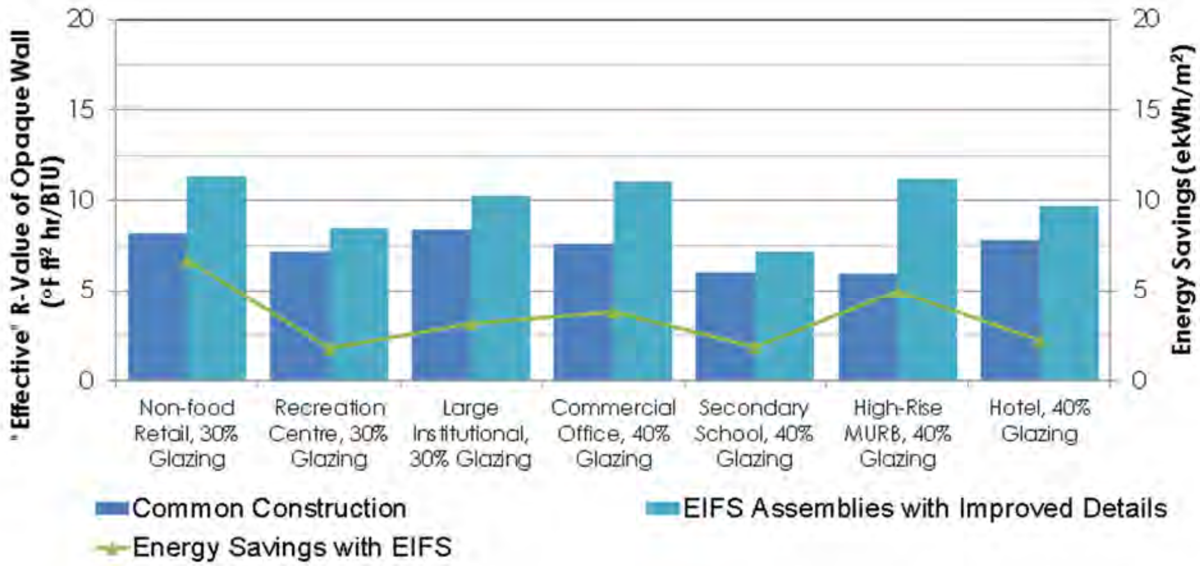


Figure 3.17: Comparison of Common Exterior Insulated Steel Stud Walls to the EIFS Wall Assemblies with Improved Details for all the Archetype Buildings for Vancouver (Except Low-Rise MURB)

3.2.10 THE BOTTOM LINE

Key lessons or significance that can be gleamed from the cost-benefit analysis that is not covered in the sections above include:

- Split and interior insulated assemblies are not only inefficient from an assembly perspective, but are shown to be even more inefficient when the impact of interface details is included in determining an overall U-value. More energy savings can be realized with exterior insulated assemblies than compared to split insulated assemblies. (For results, refer to Scenario 1, compare between base Case 1 and Case 1B, in Appendix E).
- Sometimes a small amount of insulation in a gap makes a difference. For the thermally broken balconies, insulating the curb has an impact that requires attention. (For results compare details 5.2.11 to 5.2.16).
- The key finding that more attention needs to be paid to interface details is a recommendation that applies to all the building sectors. The interface details had more of an impact on some types of buildings and less on others, but the impact is significant for all the buildings.
- Ground heat flow is important for low-rise buildings, which is a large percentage of buildings. Ground heat flow is highly transient and questions remain how prevailing methods relate to reality. Only a few details were evaluated for this guide, but thermal bridging the at-grade transition can significantly impact the overall U-value for low-rise buildings.
- More work could be done to evaluate the impact of thermal mass for our climate with respect to 3D heat flow and the impact on peak loads (Refer to Appendix C for discussion on the impact of thermal mass).

- Not all building types have been thoroughly addressed by this study. One type of building to be more thoroughly addressed is metal buildings and particularly the impact of the roof to wall and wall base interfaces.
- A focus of this guide was on codes and energy standards and how they relate to new-construction. The same methodology and data can be applied to existing buildings to mitigate thermal bridging. For existing buildings, different factors affect costs than for new construction that will need to be evaluated. The concept of payback is also more appropriate for existing buildings than for new construction.
- The details categorized as regular or poor are ubiquitous in BC construction. Some details and assemblies are more common for certain types of buildings (such as balconies and window-wall), and primarily apply to residential buildings and hotels; whereas, conventional curtain-wall applies more to large institutional buildings, recreation centres, and commercial offices. A summary of the use of the assemblies in the different building sectors is shown in Table 3.9.

Table 3.9: Common BC Assemblies and Elements

Catalogue Index	Assembly / Element	Common Building Type	Relative Use in BC
1.	Window-Wall	Hotel, Mid- and High-Rise MURB's	high
2.	Conventional Curtain-Wall and Structural Beam Penetrations	Large Institutional Buildings, Recreation Centres, Commercial Office	high
3.	Unitized Curtain-Wall	Commercial Office, Mid- and High-Rise MURB's	medium
4.	High Performance Curtain-Wall	Large Institutional Buildings, Commercial Office, Hotel	low
5.	Steel Framed Walls with Metal Panel	Large Institutional Buildings, Schools, Recreation Centres, Commercial Office, Hotel, Mid- And High-Rise MURB's	high
5.	Steel Framed Walls with Stucco	Schools, Recreation Centres, Hotel, Mid- and High-Rise MURB's	high
6.	Poured-In-Place Concrete Walls	Large Institutional Buildings, Recreation Centres, Hotel, Mid- and High-Rise MURB's	high
6.	Precast Concrete	Large Institutional Buildings, Schools, Recreation Centres, Commercial Office, Hotel, Mid- and High-Rise MURB's	medium
7.	Wood-Frame Construction	Wood-Frame MURB's	high
8.	Concrete Balconies	Hotel, Mid- and High-Rise MURB's	high
9.	Sloped Metal Roofs	Schools, Recreation Centres, Hotel, Mid- and High-Rise MURB's	medium

3.3 NEXT STEPS

Current energy standards adopted by jurisdictions need to evolve or risk being dropped by those jurisdictions and replaced with competing energy codes and standards that are more effective in meeting their energy goals. Regulators have to recognize that prescriptive requirements based solely on providing the required insulation R-values and corresponding assumed assembly U-value is not enough for non-combustible buildings. Market transformation will lead from the development and adoption of code requirements that require thermal bridging at interface details to be considered during design. Enforcement will be the key for ensuring that any new code requirements are adopted by industry as accepted practice. The objective of changes to the codes should be:

- Improve the ability to enforce the code and level the playing field by adding clarity.
- Adopt requirements that make sense for our climate and construction practice.
- Replace “exceptions” based on wall areas with metrics that represent heat flow like linear transmittance or remove all exceptions.
- Create incentives and reward improved details when practical.
- Encourage good practice and a holistic design approach.
- Use this guide to help policy and authorities implement programs that are more enforceable.

Once adopted, it will be the responsibility of many of the leading stakeholders to get the information out to the wider industry. This includes government and policy makers, engineering/architectural associations and utility companies. This could be done through:

- Technical bulletins on specific and targeted areas of interest.
- Increase awareness through presentations and publications.
- Training and workshops based on the process set forth in this guide.

Even with the publication of this extensive guide, further work is needed to better the industry’s understanding of the effects of thermal bridging. This can include:

- Extending this work to other climates and jurisdictions to support development of national codes and standards.
- Revise current methodologies and standard procedures for evaluating spandrel panels.
- Create local interpretation bodies for the enforcement of energy standards.
- Implement methodology and information into energy modeling software. This is key to the ease of implementation into current practice.

For utility companies, there are many opportunities to incentivize good practice if it means a more efficient use of energy. Utilities can:

- Implement programs to incentivize upgrades for existing buildings during major retrofits or rehabs or for new construction.
- Target specific sectors where the envelope matters most (residential, low-rise commercial buildings).
- Create design guides for projects following utility incentive programs.

For the design teams, accounting for thermal bridges, if not done already, should be on the radar of every member. For those team members whose work can be directly affected by thermal bridging:

- Become a more integrated part of the design team by increased awareness of the impact of thermal bridging on the building envelope thermal performance.
- Use this guide to provide information to the design team. This may include thermal performance, but it can also be used to help clarify roles and responsibilities on a project.