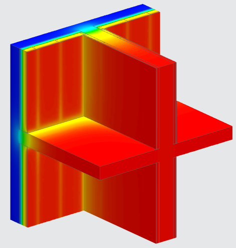
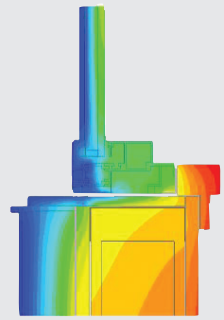
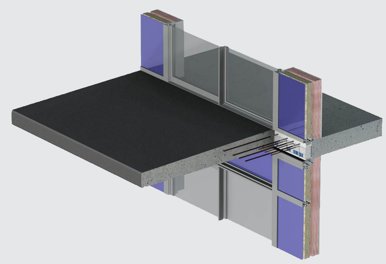
Morrison Hershfield







Canadian Consulting Engineering Awards

Building Envelope Thermal Bridging Guide

2015

Project Sponsors:

BC Hydro Power Smart

Homeowner Protection Office (a Branch of BC Housing)

Canadian Wood Council

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Building Envelope Thermal Bridging Guide

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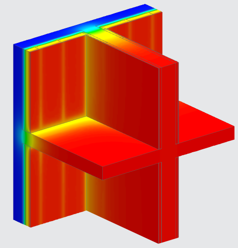

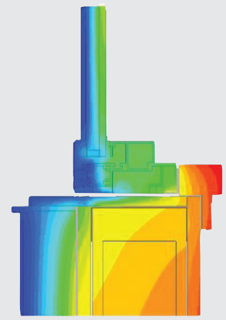

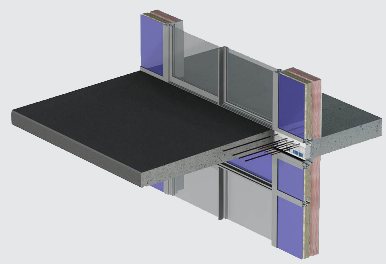

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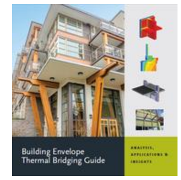
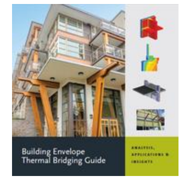


The *Building Envelope Thermal Bridging Guide* seeks to transform the building industry by facilitating the design and construction of more thermally efficient building envelopes. The Guide, developed by Morrison Hershfield in collaboration with sponsors BC Hydro Power Smart, Homeowner Protection Office (HPO) – a Branch of BC Housing, Canadian Wood Council, FortisBC and FPInnovations, aims to overcome obstacles confronting industry with respect to mitigating thermal bridging to reduce energy consumption in buildings.

A complex subject and set of problems was distilled into an easily understood and practical guide that fills a previous information gap, providing essential information for evaluating building envelope thermal performance, including easy-to-use methods for understanding, accurately calculating and mitigating thermal bridging.

The guide is of great interest to practitioners, researchers and regulators. It outlines how to effectively account for thermal bridging and provides an extensive catalog of common building envelope assemblies and interface details and their associated thermal performance. It contains a cost-benefit analysis and discussion on significance and further insights. Technically sophisticated and complex information is presented in a practical, user-friendly manner.

With its local and international significance, this groundbreaking reference tool has already begun to influence building design, construction, policy and the development of energy codes and standards in BC and beyond. When implemented, the guide will affect positive change in building envelope design and performance, resulting in more energy efficient buildings and a more sustainable future for generations to come.



INNOVATION

"Ever heard some old-timer describe what life was like before AutoCad? That might be exactly what today's engineers sound like in a year or two, telling the youngsters how difficult it used to be to calculate energy performance in the days before the *Building Envelope Thermal Bridging Guide*." - Robin J. Miller, Innovation Magazine

The thermal performance of a building's envelope can be greatly affected by thermal bridging, or localized areas of high heat flow through walls, roofs and other insulated building envelope components. In the past, resources that allowed practitioners to accurately account for thermal bridging were limited and it was not effectively addressed in energy standards (either overlooked or exempted). Research and monitoring of buildings is increasingly showing the importance of mitigating the impact of thermal bridging which can be significant to building energy consumption, the risk of condensation on cold surfaces, and occupant comfort.

An earlier study carried out by Morrison Hershfield, ASHRAE 1365-RP "Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings", put forward procedures and data that allowed practitioners to evaluate the impact of thermal bridging. This started a market transformation to better evaluate building performance but only scratched the surface in terms of identifying how to effectively mitigate thermal bridging in design and did not address the impact on energy consumption in buildings.

The *Building Envelope Thermal Bridging (BETB) Guide*, developed by Morrison Hershfield in collaboration with project sponsors, expands significantly on previous work, and identifies where opportunities exist to incentivize improving industry practice. Emerging technologies and construction practices that offer substantial improvements to current construction practice are also explored.

Morrison Hershfield used a "state of the art" high tech tool to analyze a complex set of problems to provide practical engineering solutions that industry can easily implement. Although the tools, expertise and software were available to provide solutions for every variable to multiple decimal places, it was recognized that industry needed engineering solutions rather than scientific explanations.

In developing the methodology for the Guide, Morrison Hershfield explored a myriad of variables in a manner that facilitates understanding of what is important and how to practically address thermal bridging in energy standards. Adjustments were made to the methodology to accommodate new information, new insights and validate against available lab measurements. The result is a robust methodology that industry can implement with confidence.

Although the introduction of new concepts and a call for change can sometimes be threatening, this groundbreaking reference tool has already begun to influence change. The overwhelming positive "buzz" regarding the BETB Guide received by industry across North America has resulted in a commitment from co-sponsors to making it a living document. The Guide has momentum for continued acceptance because of its technical excellence, the breadth of information within, and the way essential information is clearly communicated for a multitude of industry stakeholders.

COMPLEXITY

Before the BETB Guide, significant thermal bridges were often overlooked due to the complexity and time required to fully assess building envelope thermal performance. A "state of the art" high tech tool was used to analyze a complex set of problems and provide practical, implementable engineering solutions. Investment in resources,

software and staff facilitated not only the delivery of this comprehensive assignment on time, but exceeded client expectations for breadth and quality of information.

In developing the guide, Morrison Hershfield evaluated over 300 building envelope details (in 3D) that are directly relevant to construction in North America. The thermal performance of building envelope details was quantified using an extensively calibrated and validated 3D heat transfer model. This specialized heat transfer software is not commonly used in the building industry, but is relied on in other applications where accuracy and the ability to evaluate many design iterations is paramount (such as for the design of the Mars rover, electronics and automobiles.)

An extensive catalogue of details was developed, allowing designers quick and straightforward access to information intended to mitigate thermal bridging, including some emerging technologies. Costs associated with improving building envelope thermal performance were examined, and the energy impact was forecasted for several building types and climates using whole building energy models (EnergyPlus) of archetype buildings. Finally, the energy cost benefit was evaluated for improving the building envelope compared to other strategies such as higher insulation levels and high performance glazing.

The end result is a practical guide that is broken into three stand-alone parts. Part 1, the "Building Envelope Thermal Analysis (BETA) Guide", is of great value to practitioners as it outlines how to effectively account for thermal bridging. Also for practitioners, Appendices A & B provide a catalogue of common building envelope assemblies and interface details and their associated thermal performance data. Part 2: Energy Savings and Cost Benefit Analysis and Part 3: Significance, Insights and Next Steps, along with Appendices C, D and E will appeal to researchers and regulators, since they contain the cost-benefit analysis and discussion on the significance and further insights of using the guide to mitigate thermal bridging in buildings.

SOCIAL AND/OR ECONOMIC BENEFITS

The BETB Guide will lead the way to constructive changes in the building industry. For the first time, modelers, architects, designers and others will have a comprehensive catalogue of building envelope details and a comprehensive guide that will provide an easy to understand process to account for major building envelope thermal bridges.

The ability to more quickly, accurately and easily account for the building envelope thermal performance will help to transform the marketplace so that new buildings are designed and built to higher standards of energy efficiency. Beyond reducing heating and cooling loads, mitigating thermal bridging will also increase comfort for building occupants and reduce condensation which can extend the life of the building envelope.

BC Hydro's Gordon Monk is confident that the BETB Guide is a critically important resource for builders and industry professionals. "…it will ultimately benefit the people who buy and live and work in the units the new construction industry builds. It's also a great educational tool for up-and-coming industry professionals."

In a practical sense, the BETB Guide will make life a lot easier for those involved in new building design. "It used to take me two whole weeks to calculate the performance of a building envelope, with plans all over the floor, colour crayons everywhere. Fast forward to today and BC practitioners now have access to the latest in modern technology to calculate energy performance in far less time and with far greater accuracy." – *Greg McCall, City of Vancouver*

ENVIRONMENTAL BENEFITS

Because buildings consume a large percentage of electricity and natural gas, improved energy conservation in buildings is an important approach to reduce energy consumption and greenhouse gas emissions. In Canada, space conditioning (primarily heating) is one of the largest components of energy use in commercial, institutional, and residential buildings. 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.

The additional heat flow due to thermal bridging at interface details can add up to be a significant portion of the heat flow through the building. If major thermal bridges are not addressed then adding insulation to building envelope assemblies may not provide significant benefits and may go against energy standards where cost benefit must be a consideration. The BETB Guide hits this point squarely for policy makers to consider for future iterations of codes and standards.

If decisions are being made based on calculations that ignore significant heat loss paths then there is a high probability that materials are not being used efficiently, which does not fit well with the goal of truly sustainable buildings and reducing embodied energy. When implemented, the BETB Guide will affect positive change in building envelope design and performance, resulting in more energy efficient buildings and a more sustainable future for generations to come.

MEETING CLIENT'S NEEDS

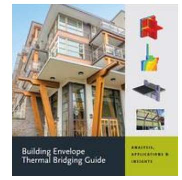
The client's primary goal was to provide information that makes it easier for thermal bridging to be comprehensively considered in building codes, design and whole building energy simulations. Adherence to a strict schedule and the creation of a legacy project were very important objectives.

The reaction from industry leaders has been excellent. "The work your team has produced is some of the clearest, most useful I have seen on the subject of thermal bridging in envelopes." – Justin Pockar, City of Calgary.

This project was delivered on time and on budget. In the client's own words "you guys went above and beyond in terms of both effort and quality." This success can be partially attributed to the specialized technical expertise and state of the art software behind the analysis, but also to the determination of the team, good project management and a sensible investment in resources.

The BETB Guide is considered to be a significant energy efficiency initiative. It addresses a number of obstacles currently confronting industry and outlines why and how thermal bridging should be more comprehensively considered by industry.

Greg McCall from the City of Vancouver, summed it up well when he said: "The City of Vancouver recognizes the significance of the BETB Guide as a tool that could influence the industry and policy makers, and even those developing the next level of energy standards and codes. Its approach and accuracy lends itself to be a critically useful tool, not just in BC, but across the nation and even south of the border. In a world where energy performance is increasingly becoming a priority, this tool will undoubtedly affect positive change in building envelope design and performance wherever it is used."



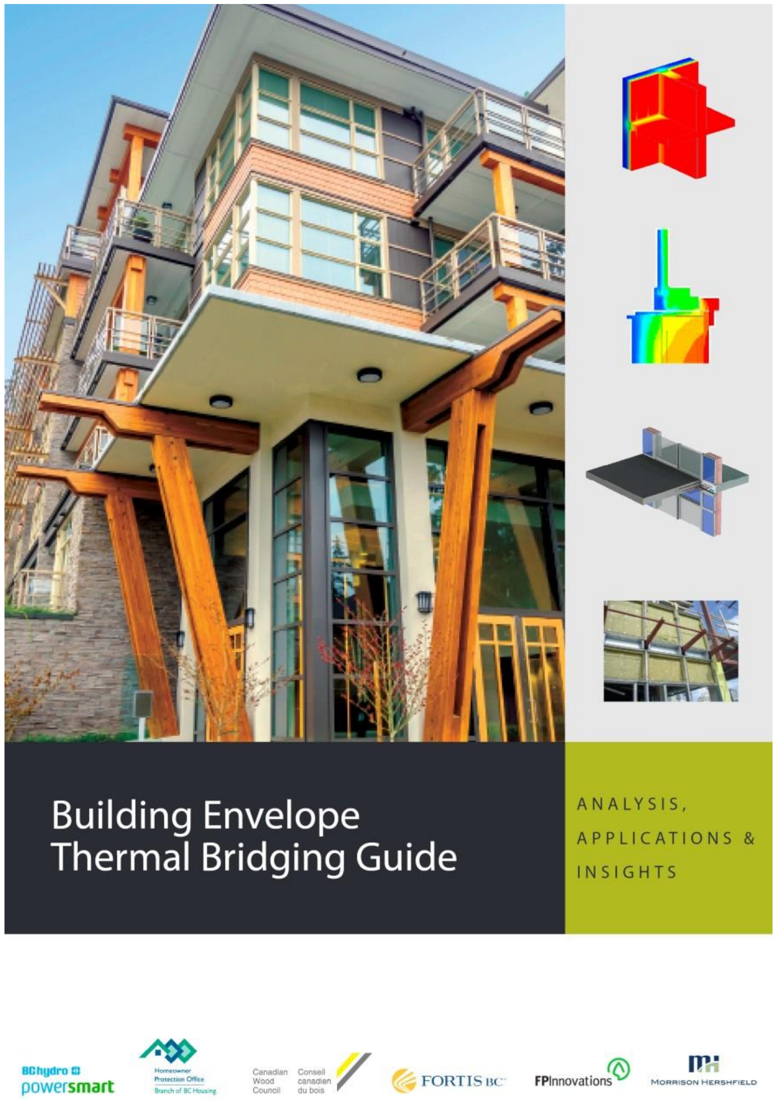


Photo 1: Building Envelope Thermal Bridging Guide.

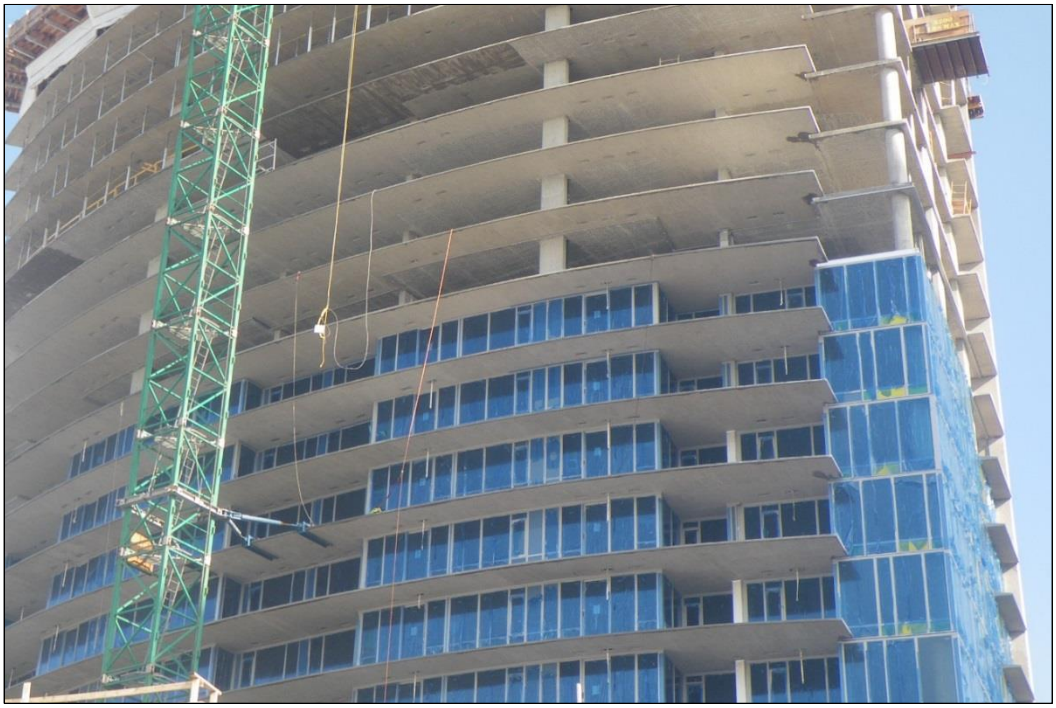


Photo 2: From BETB Guide: example of common residential high-rise with extended concrete floor slabs around perimeter and building envelope of mainly floor to ceiling window-wall.

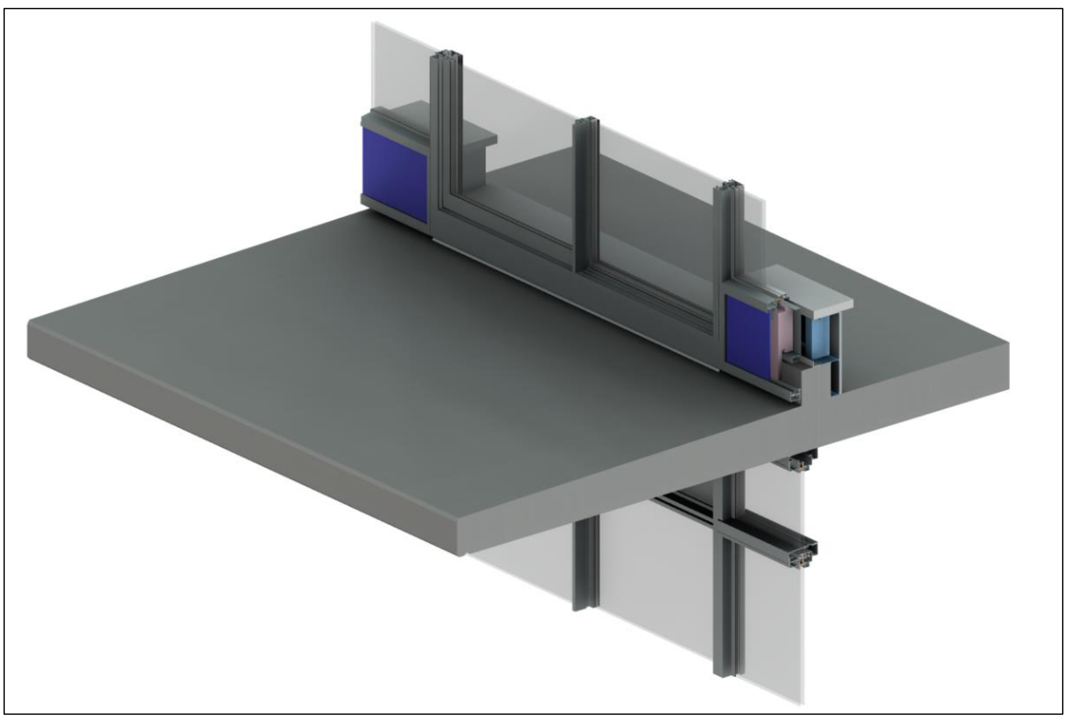
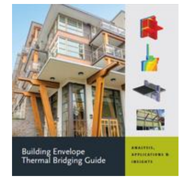


Photo 3: From BETB Guide: Sample 3D Model of a concrete balcony and window-wall as seen in Photo 2.



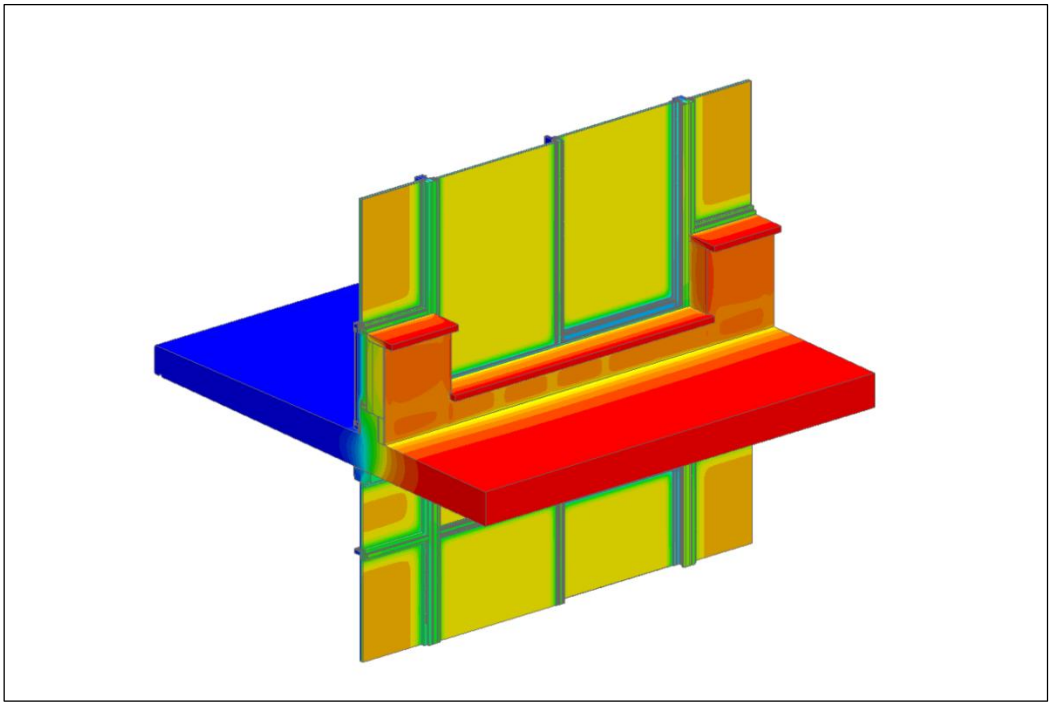


Photo 4: From BETB Guide: Example thermal image shows cold interior surfaces of concrete balcony and window-wall as seen in Photo 2.

Appendix B - Catalogue Thermal Data Sheets BUILDING ENVELOPE THERMAL BRIDGING GUIDE

Clear Wall Assemblies

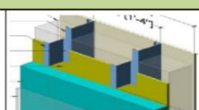
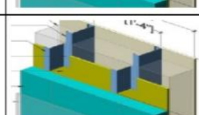
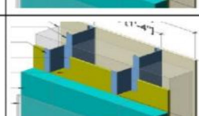
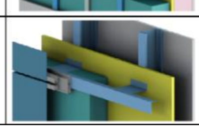
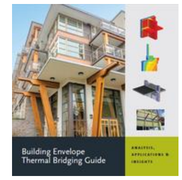
Description of Detail (Thermal Anomaly)		Construction Type	Wall Assembly Description	Detailed Description	Reference	1D Insulation	Thermal Transmittance Btu / hr ft² F	W/ m² K
Metal Clip		Steel Framed	Exterior Insulated Steel Stud	**Exterior Insulated Steel Frame Assembly** with Intermittent Vertical Z-Girts at 16" Supporting Metal Cladding	5.1.10	R-5	0.142	0.81
						R-10	0.101	0.58
						R-15	0.082	0.47
						R-20	0.070	0.40
						R-25	0.062	0.35
Metal Clip		Steel Framed	Exterior Insulated Steel Stud	**Exterior Insulated Steel Frame Assembly** with Intermittent Vertical Z-Girts at 24" Supporting Metal Cladding	5.1.10	R-5	0.136	0.77
						R-10	0.093	0.53
						R-15	0.073	0.42
						R-20	0.061	0.35
						R-25	0.053	0.30
Metal Clip		Steel Framed	Exterior Insulated Steel Stud	**Exterior Insulated Steel Frame Assembly** with Intermittent Vertical Z-Girts at 36" Supporting Metal Cladding	5.1.10	R-5	0.132	0.75
						R-10	0.089	0.50
						R-15	0.068	0.39
						R-20	0.057	0.32
						R-25	0.049	0.28
Metal Clip		Steel Framed	Interior and Exterior Insulated Steel Stud	**Interior and Exterior Insulated Steel Frame Assembly** with Vertical Clips Supporting Stucco Cladding	5.1.13	R-10	0.062	0.35
						R-15	0.054	0.30
						R-20	0.048	0.27
Clips		Steel Framed	Exterior Insulated Steel Stud	**Exterior Insulated Steel Frame Assembly** with Horizontal Clips Supporting Metal Cladding	5.1.11	R-15	0.068	0.39
						R-20	0.056	0.32
						R-25	0.049	0.28

Photo 5: Sample summary table of building envelope performance for evaluated wall assemblies per Insulation Level.



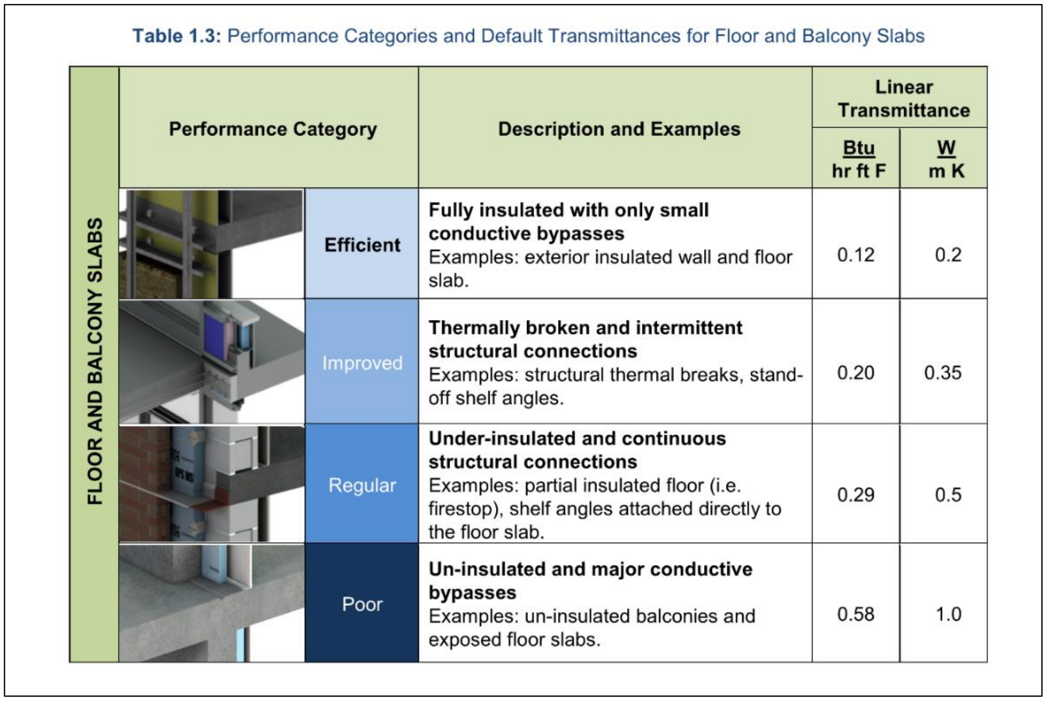


Table 1.3: Performance Categories and Default Transmittances for Floor and Balcony Slabs

FLOOR AND BALCONY SLABS	Performance Category	Description and Examples	Linear Transmittance Btu/hr ft F	Linear Transmittance W/m K
	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

Photo 6: Sample summary table of floor and balcony slab interface details. 64 Unique conditions are distilled to four (4) easy to use categories for designers.

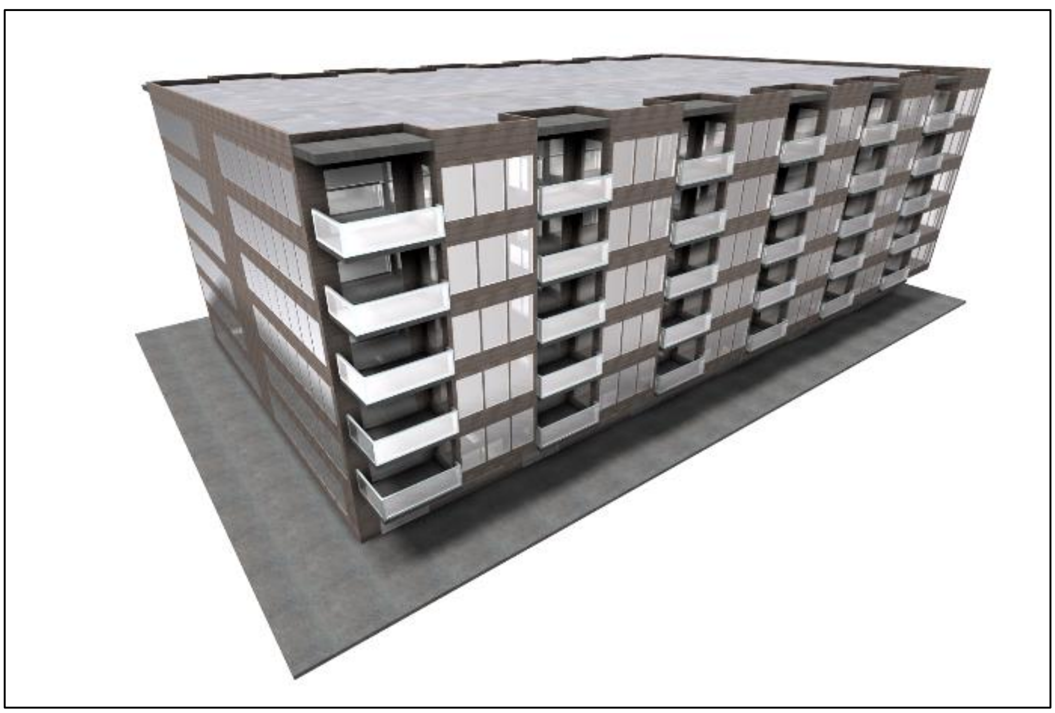
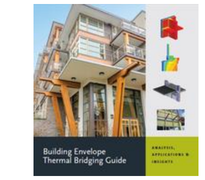


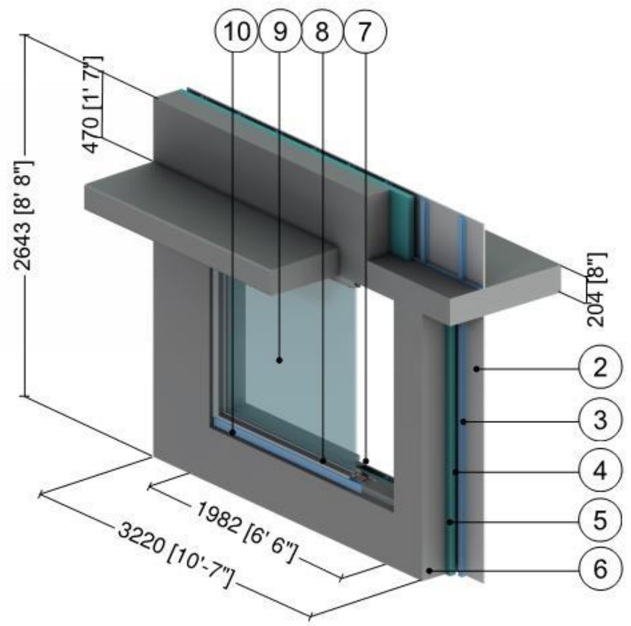
Photo 7: Sample Archetype Building (low-rise residential) used in cost benefit analysis for evaluating how the building envelope can be improved with better details vs other strategies.

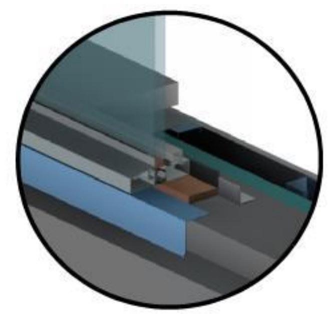


SAMPLE BUILDING ENVELOPE PERFORMANCE DATA SHEET

Detail 6.3.3

Interior Insulated Concrete Mass Wall with 1 5/8" x 1 5/8" Steel Studs (16" o.c.) Supporting Interior Finish – Window & Projected Slab Intersection





Window Sill Detail

Window Head Detail

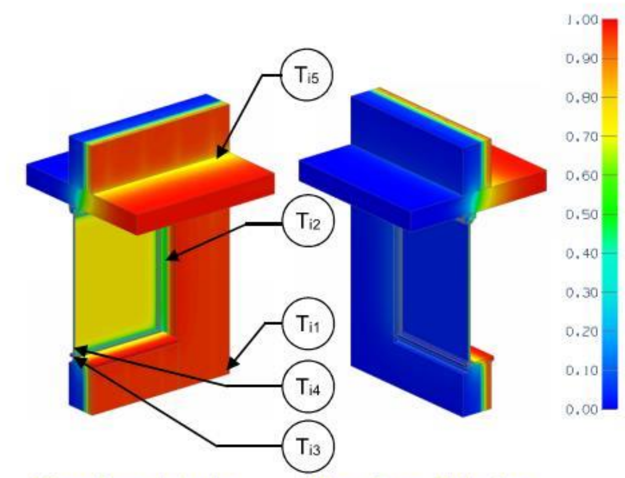
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film[1]	-	-	R-0.6 (0.11 RSI) to R-1.1 (0.20 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	1 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	1 5/8" (92)	-	R-0.9 (RSI-0.16)	0.075 (1.2)	0.24 (1000)
5	Continuous Rigid Insulation	Varies	-	R-10 (1.76 RSI) to R-15 (2.64 RSI)	1.8 (28)	0.29 (1220)
6	Concrete Wall/ Projected Floor Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
7	Steel Sheet Connected to Studs	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Wood Sill	1 1/4" (30)	0.69 (0.1)	-	27.8 (445)	0.45 (1880)
9	5' (1.5m) x 6' (1.8m) Aluminum window: double glazed & thermally broken, double glazed IGU U_{IGU} = 0.32 BTU/hr.ft².°F (1.82 W/m²K)[2]					
10	Aluminum Flashing	14 Gauge	1109 (160)	-	171 (2739)	0.21 (900)
11	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within framing was found using ISO 100077-2

Building Envelope Thermal Bridging Guide

Detail 6.3.3

Interior Insulated Concrete Mass Wall with 1 5/8" x 1 5/8" Steel Studs (16" o.c.) Supporting Interior Finish – Window & Projected Slab Intersection



View from Interior View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-2.9 (0.51 RSI) + interior insulation
Transmittance / Resistance without Anomaly	U_w, R_w, U_g	"clear wall" U- and R-value: w = concrete wall without slab; g = glazing
Transmittance / Resistance	U_s, R_s, U_t, R_t	U and R-values for: s = wall + slab; t = combined wall + slab + window
Surface Temperature Index[1]	T_i	0 = exterior temperature; 1 = interior temperature
Linear Transmittance	ψ_s, ψ_g	Incremental increase in transmittance per linear length of: s = slab; g = glazing transition

[1]Surface temperatures are a result of steady-state conductive heat flow with constant heat transfer coefficients. Limitations are identified in final report.

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Concrete Clear Wall

Interior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_w ft²·hr·°F / Btu (m² K / W)	U_w Btu/ft² ·hr ·°F (W/m² K)
R-10 (1.76)	R-12.9 (2.28)	R-12.3 (2.16)	0.082 (0.46)
R-15 (2.64)	R-17.9 (3.16)	R-17.3 (3.05)	0.058 (0.33)

Base Assembly - Glazing

$U_{centre\ of\ glass}$ Btu/ft² ·hr ·°F (W/m² K)	U_g Btu/ft² ·hr ·°F (W/m² K)
0.321 (1.82)	0.400 (2.27)

Slab Linear Transmittance

Interior Insulation 1D R-Value (RSI)	R_s ft²·hr·°F / Btu (m² K / W)	U_s Btu/ft² ·hr ·°F (W/m² K)	ψ_s Btu/ft² ·hr ·°F (W/m² K)
R-10 (1.76)	R-7.4 (1.3)	0.135 (0.77)	0.499 (0.864)
R-15 (2.64)	R-9.1 (1.6)	0.110 (0.63)	0.471 (0.815)

Window Transition Transmittance

R_t ft²·hr·°F / Btu (m² K / W)	U_t Btu/ft² ·hr ·°F (W/m² K)	ψ_g[2] Btu/ft ·hr ·°F (W/m K)
R-3.1 (0.55)	0.320 (1.82)	0.290 (0.502)
R-3.3 (0.58)	0.305 (1.73)	0.298 (0.515)

[2]For the linear transmittance, use the window perimeter

Temperature Indices

	R10	R15	
T_{i1}	0.07	0.05	Min T on concrete, away from window slab and studs
T_{i2}	0.57	0.56	Max T on concrete along window jamb
T_{i3}	0.31	0.31	Min T on window frame, at bottom middle of glazing
T_{i4}	0.34	0.36	Min T on window glass, at bottom middle
T_{i5}	0.34	0.33	Min T on Slab, bottom of slab along wall, away from window