Considerations for Exterior and Split Insulated Net-Zero Energy Ready Wall Systems

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Code Requirements Moving Towards Net-Zero

With pressing concerns over climate change, government authorities across Canada are implementing tougher energy code requirements across numerous sectors to curb our greenhouse gas emissions. As a key driver in emissions, the building industry is undergoing a fundamental shift in focus towards drastically better energy efficiency from both new and existing buildings.

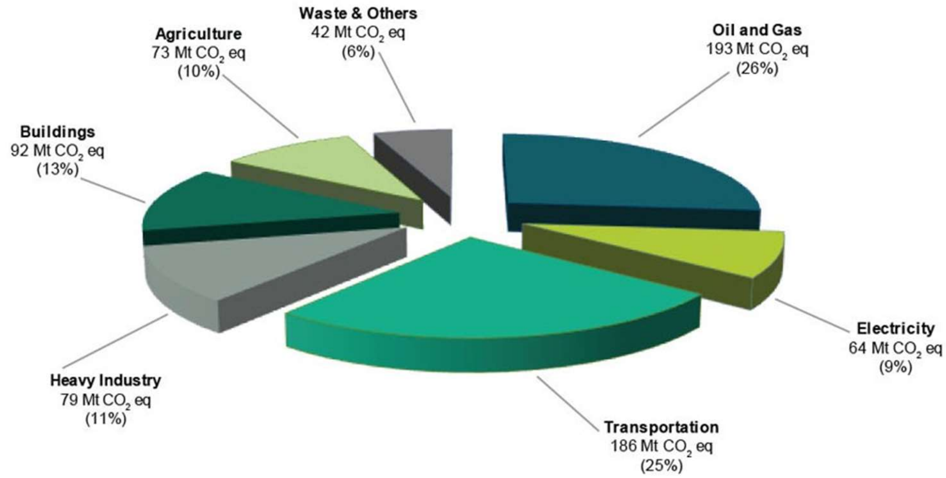


Figure 1: Sources of Greenhouse Gas Emissions in Canada (Environment and Climate Change Canada, 2020)

Canada's commitments to the Paris Climate Accords and other international agreements have prompted numerous national policy changes to meet our emission reduction commitments.

The Pan Canadian Framework on Clean Growth and Climate Change outlines specific policy targets related to the built environment; the most impactful being:

Federal, provincial, and territorial governments will work to develop and adopt increasingly stringent model building codes, starting in 2020, with the goal that provinces and territories adopt a "net-zero energy ready" model building code by 2030.

Net-Zero Energy Ready (NZER) buildings require so little added energy to operate they could potentially rely on small scale, on-site renewable energy generation to supply the building's needs.

Currently, jurisdictional authorities across Canada are at different stages of developing, implementing, or updating Net Zero Energy Ready (NZER) targets into their energy codes. Two leading examples of NZER code frameworks that have already been implemented in Canada are the BC Energy Step Code and the Toronto Green Standard V3. There are also voluntary standards such as Passive House that promote similar objectives. The 2020 version of the National Energy Code for Buildings (NECB) will also include a NZER pathway into the compliance paths, which could be adopted by various provinces during the next code cycle.

Reduced energy use to meet these energy code targets will require a wholesale change to conventional design and construction. Design strategies, energy systems, and construction practices that were once relied on to meet past energy targets will no longer be sufficient. As codes shift away from prescriptive methods towards performance-based methods, the design community will have to respond with a comprehensive transformation of their designs that includes assessing each energy system for its interactive impacts on overall energy use.

NZER Codes – Impacts on the Building Envelope

A key component of any NZER design will be the expectation for much higher building envelope thermal performance. The building envelope, including the walls, roofs, floors and glazing systems, has a major impact on the energy required for space heating and cooling. Higher levels of effective insulation and building air tightness will result in less energy being required to keep the interior comfortable. This is good, basic, logical building science.

Prescriptive targets for envelope assembly thermal performances in codes like the NECB have become more stringent with each code update. But each of these performance criteria is identified independently of the others, which can make it difficult to adhere to a prescriptive approach to design.

The best energy saved is the energy you don't need illustrates the importance of the building envelope.

The upcoming NZER codes are pushing towards performance paths for compliance. Performance-based compliance paths can allow more flexibility between energy systems. However, designers must expect higher thermal resistance from all envelope assemblies as we strive for NZER, regardless of the compliance method. It simply makes sense.

Table 3.2.2.2.
Overall Thermal Transmittance of Above-ground Opaque Building Assemblies
Forming Part of Sentences 3.2.2.2.(1) and (2)

Above-ground *Opaque Building Assembly*	Heating Degree-Days of *Building* Location,(1) in Celsius Degree-Days					
	Zone 4:(2) < 3000	Zone 5:(2) 3000 to 3999	Zone 6:(2) 4000 to 4999	Zone 7A:(2) 5000 to 5999	Zone 7B:(2) 6000 to 6999	Zone 8:(2) ≥ 7000
	Maximum *Overall Thermal Transmittance*, W/(m²·K)					
Walls	0.315	0.278	0.247	0.210	0.210	0.183
Roofs	0.193	0.156	0.156	0.138	0.138	0.121
Floors	0.227	0.183	0.183	0.162	0.162	0.142

Figure 2: Prescriptive Requirements for Building Assemblies by Climate Zone from NECB 2017

As shown in Figure 2, effective USI 0.247 (R-23) walls were currently suitable in cold climates in Canada when balancing energy and cost. But to achieve NZER, wall assemblies will have to aim for effective R30-R40. This pushes these assemblies to use significantly thicker or higher performance insulations in different combinations than what is used today.

Thermal Bridging Through the Envelope

Getting these effective performance levels from the envelope will not only mean much thicker insulation levels, and a greater recognition of the impacts of thermal bridging. Thermal bridging through insulating layers can significantly reduce an assembly's overall thermal performance and must be prevented wherever possible.

Thermal bridging can occur in building assemblies due to repeating structural members like studs and cladding attachments, and also from interface details between assemblies, such as balconies, window-to-wall interfaces, parapets, and through-wall flashings. For larger buildings that use steel and concrete construction, unmitigated thermal bridging from interface details can be detrimental in achieving wall performance targets and could more than *double* the expected heat flow through the envelope. This can lead to a significant increase in energy demand.

Thermal bridging matters, especially as we reach for Net Zero Energy Ready.

The Holistic Approach

For evolving NZER codes and performance path projects, the targets for envelope assemblies will vary from project-to-project and will be dependent on all energy design requirements. These relationships are captured in the whole building energy model.

To keep performance targets for building envelope assemblies rational, the entire building design needs to be looked at and optimized in an integrated fashion – not just the wall systems. This includes:

- Efficient building shapes → lower surface area-to-volume ratios
- High heat recovery ventilation (HRV) efficiency → 70%+
- Reduced air leakage → very airtight over the whole building
- High glazing performance → less than USI 1.4
- Lower window-to-wall ratios → less than 40%
- Low thermal bridging, especially at window-to-wall transitions

In reaching for greater energy efficiency from our building envelope, it's also important not to lose sight of constructability and cost. Providing a performance buffer during design will allow for greater flexibility for systems, especially during tendering.

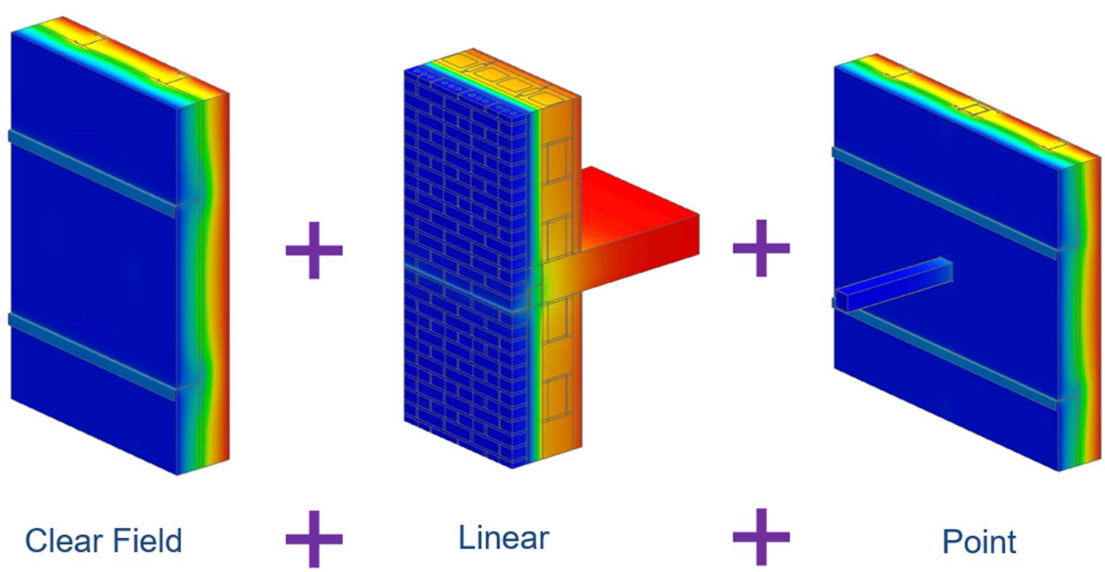


Figure 3: The Three Heat Flow Components of any Building Envelope Assembly. Add all of the items to create the overall heat flow through the assembly.

Comprehensive thermal bridging calculations, including the impacts of thermal bridging from assemblies and details, are becoming required across Canada for energy code compliance. NECB 2017 Section 3.1.1.7 and Vancouver Energy Modelling Guidelines both outline the thermal bridges to be included.

For example, for the vertical opaque walls, U-value targets in prescriptive tables or from project energy models are not just for the walls but for the combined wall + interface details. This has significant implications on wall system design as this was not previously included, especially in the prescriptive path.

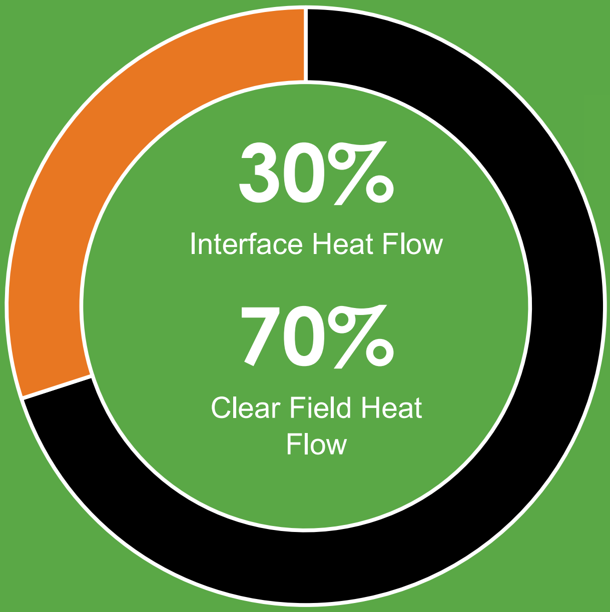
For more detailed information on thermal bridging and calculations, please see the *Building Envelope Thermal Bridging Guide*[1].

1 https://thermalenvelope.ca BCHousing and Morrison Hershfield

Preliminary Wall Targets for New Construction Buildings

Building envelope energy performance targets are set early in the project in the energy model. This is often before details and assemblies have been developed. It is important to set realistic targets to start so designs are not forced towards a specific approach or expensive solution during design development. To determine what the average effective R-value for just the wall assembly should be, based on the target for the overall vertical opaque envelope, see the formula below.

With regard to thermal bridging, its recommended to keep the Heat Flow Factor, the additional heat flow caused by interface details to ~0.3 (30%). This way the insulation thickness for wall assemblies can be optimized. To provide flexibility for the project, it may be prudent to be more conservative and use a higher factor like 0.5 (50%) during early design and refine lower during design development.



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

where

R_o = clear field effective R-value target

R = overall opaque envelope R-value

x = interface detail Heat Flow Factor

Exterior Insulated Wall Assemblies

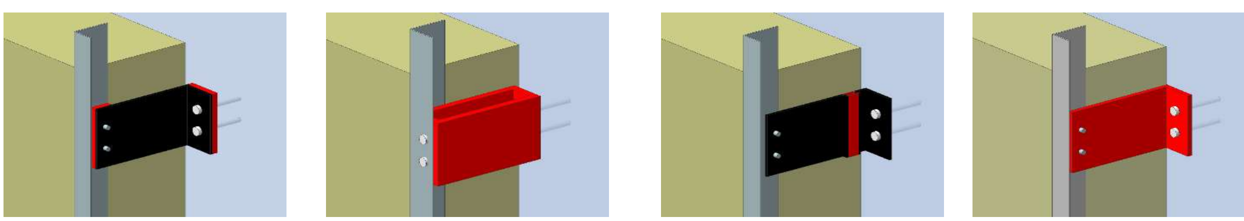
Minimizing thermal bridging in the wall assemblies will be critical. For example, solely placing insulation within the steel stud cavity will return less than 50% of the insulating value of that insulation due to the heat flow through the steel studs. To combat these thermal bridging losses, many wall designs have moved toward using insulation on the exterior of the wall studs, with intermittent cladding attachment systems. This approach can provide numerous advantages.

There are a wide variety of thermal clip cladding attachment systems available. In general, placing insulation on the exterior side of the sheathing with an intermittent thermal clip cladding attachment system can result in overall thermal resistance losses of only 10-30%, instead of the 50-60% seen within the studs. Careful selection and arrangement of the clips will help keep losses to a minimum.

Thermal Clip Systems and Insulation

In choosing a cladding attachment system, the thermal performance of the clip itself is only one aspect of the overall wall thermal performance. To accurately compare one system to another, designers should be mindful of project specific conditions, such as:

- Structural performance – Project structural requirements will determine clip spacings. A clip system with higher structural capacity means larger component spacings, fewer materials, and less thermal bridging.
- Layouts – Cladding systems have different requirements for connection points and the number of clips may be set by the panel layouts. Efficiencies may be found in utilizing an efficient sub-structure layout
- Combustibility – Many materials used for thermal breaks may be considered combustible. Certain systems may not be acceptable to the authority having jurisdiction without testing or be approved as an alternate solution
- Constructability – Ease of installation and adjustability is a key factor for any cladding system. A more complex or non-adjustable system may increase labour and cost.



Metal Brackets with Thermal Break Pads | Low Conductivity Spacer with Through Fasteners | Metal Brackets with Integrated Glazing-Style Thermal Break | Low Conductivity Spacer with Fasteners Behind Insulation

Figure 4: Typical Intermittent Cladding Attachment Systems

A major thermal bridge on many mid- and high-rise projects is the intermittent floor slab interface, where the concrete structure can be left exposed or only partially covered along the perimeter of the building. Exterior insulated wall assemblies allow for insulation to be run continuously across the slab edge to reduces thermal bridging.

Exterior insulated assemblies also allow for the simplification of the air barrier and vapour barrier systems. With all the insulation on the exterior, the interior wall cavity remains warm, reducing risks of condensation and moisture inboard of the exterior sheathing. This allows the air and vapour barrier to be combined on the exterior face of the sheathing and can simplify detailing of these barriers at critical junctions and interfaces. It can also reduce labour and material costs.

The biggest disadvantage of placing all of the thermal resistance on the exterior of the sheathing is that the overall wall assembly increases in thickness. However, as we move towards net zero energy buildings and more stringent energy codes, the amount of thermal resistance needed to achieve high performance buildings is significantly larger than is in common practice today.

Optimizing Wall Systems with Split Insulation

There are many ways to design and optimize wall systems for thermal performance, and there are also many project-specific factors that influence the appropriate solution.

A. For some projects, it will be keeping material and labour costs as low as possible, which may drive a project towards designing for a lower performance wall system to allow more flexibility and options during tender.

B. For other projects, schedule to completion is the concern and the walls will use prefabricated systems as the basis of design.

C. In other cases, it could be the structural requirements that will dominate what wall systems can be used.

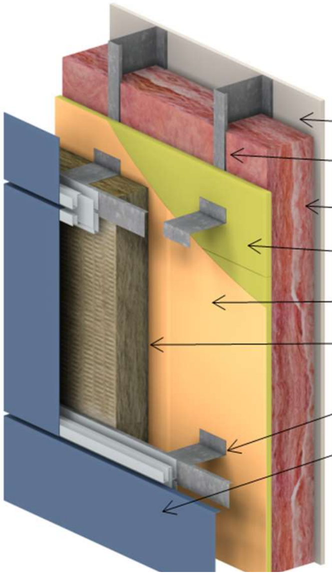


Figure 5: Typical Split Insulation Wall Assembly

D. For some projects, the overall wall thickness can be a major concern. Projects limited by their proximity to other buildings require careful consideration of wall thickness and composition to ensure sufficient useable floor space to make the project financially viable. There could be project limitations for allowable floor space area, or setback and lot restrictions, all of which could conflict with utilizing very thick walls.

Currently, for steel stud walls, placing all the insulation all on the exterior with an intermittent clip system for the cladding is common. However, achieving an effective R-30 or more with an exterior insulated wall assembly would require a significant insulation thickness. This could be at least 200-250mm (8”-10”) of insulation, depending on the insulation type and cladding attachment system used. When coupled with panel cladding and 150mm thick steel stud walls, the overall wall thickness can easily extend beyond 450mm (18”) or more. This can be limiting or unfeasible on many projects.

Achieving higher thermal performance with less thick walls is where a split insulation wall assembly can provide advantages. While not theoretically as thermally efficient as exterior insulation alone, adding insulation within the stud cavity can provide enough of an R-value improvement to allow a reduction in exterior insulation thickness (and overall assembly thickness) while still meeting minimum thermal performance. The steel stud cavity is already in place, and though filling it with insulation is not the most efficient thermal approach in isolation, it can result in a wall that meets both project energy and thickness requirements.

A good comparison of relative thermal performance versus wall thickness is provided in Figure 6. The analysis was conducted using finite element 3D heat flow modelling on a 38 x 140 steel stud wall assembly using thermally efficient cladding supports through the exterior insulation.

Scenario	Exterior Insulation Thickness (inches/mm)		Exterior Insulation *Nominal* R-value (R, RSI)		Overall Assembly *Effective* Thermal Performance				Highest Applicable Climate Zone (NECB 2015)
					R-value (R, RSI)		U-value (U, USI)		
Empty Stud Cavity	2"	(51)	R-8.6	(1.51)	R-10.2	(1.80)	0.098	(0.557)	None
	5"	(127)	R-21.5	(3.79)	R-18.0	(3.16)	0.056	(0.316)	None
R-19 Batt Insulation in Stud Cavity	1.5"	(38)	R-6.5	(1.14)	R-17.1	(3.01)	0.059	(0.333)	None
	2"	(51)	R-8.6	(1.51)	R-18.2	(3.20)	0.055	(0.313)	4
	3"	(76)	R-12.9	(2.27)	R-20.5	(3.60)	0.049	(0.278)	5
	4"	(102)	R-17.2	(3.03)	R-23.2	(4.09)	0.043	(0.245)	6
	5"	(127)	R-21.5	(3.79)	R-25.8	(4.54)	0.039	(0.220)	6
R-24 Batt Insulation in Stud Cavity	1.5"	(38)	R-6.5	(1.14)	R-18.4	(3.23)	0.054	(0.309)	4
	2"	(51)	R-8.6	(1.51)	R-19.4	(3.42)	0.051	(0.292)	4
	3"	(76)	R-12.9	(2.27)	R-21.7	(3.81)	0.046	(0.262)	5
	4"	(102)	R-17.2	(3.03)	R-24.4	(4.30)	0.041	(0.233)	6
	5"	(127)	R-21.5	(3.79)	R-27.0	(4.76)	0.037	(0.210)	7

Figure 6: Comparison of Performance of a Generic Exterior Steel Stud Wall with varying levels of interior cavity insulation

Hygrothermal Considerations for Split Wall Assemblies

A split insulation wall assembly typically has a composition as shown in Figure 5. It is common practice that the weather resistive barrier (WRB) on the exterior sheathing is considered the primary plane of air tightness in the wall assembly.

Adding insulation to the interior cavity does have implications. From a building envelope performance perspective, during the cold season the potential for interior air vapour condensation on the exterior sheathing increases since the cavity insulation reduces the temperature of the exterior sheathing as warm interior temperatures are no longer in contact with the sheathing. The risk arises if interior air has moisture conditions that will result in condensation if that air touches the cooler sheathing, whether it be via vapour migration or air leakage within the cavity. If this condition exists, then the wall design would have to be modified to include an interior vapour barrier and a *vapour permeable* air barrier membrane on the exterior of the sheathing.

Air movement from the interior space to the sheathing would also have to be stopped.

The design must consider the intended moisture characteristics of the interior air and the exterior climate. During colder climate seasons, properly balancing the amount of exterior and cavity insulation can manage the risks of condensation by keeping the temperature of the exterior sheathing warmer than the temperature of the interior air when condensation forms (the “dewpoint” temperature). If the exterior sheathing is always warmer then the interior air dewpoint temperature, condensation from vapour diffusion or air leakage will not occur on the sheathing, either by vapour diffusion or interior cavity air movement.

This balancing of insulation is referred to as “insulation ratio”. When the right insulation ratio is used in a design, there is little to no concern about condensation on the exterior sheathing. This would remove the need for an interior vapour barrier and air movement control within the cavity space, assuming the sheathing membrane is airtight.

Published research by Morrison Hershfield and others shows that managing exterior sheathing condensation risk is easier and safer by utilizing insulation ratios to move the dewpoint within assemblies, rather than using membrane permeabilities and moisture control layers[1,2]. Figure 7 provides an example of the research results, which shows that it is easier to control moisture content in plywood sheathing by reducing the risk of interior air condensation through proper insulation ratios rather than worrying about whether the sheathing membrane should be vapour tight or vapour open. This makes sense since it is easier to control moisture content by preventing the water getting into the material in the first place, rather than drying it out once it gets in.

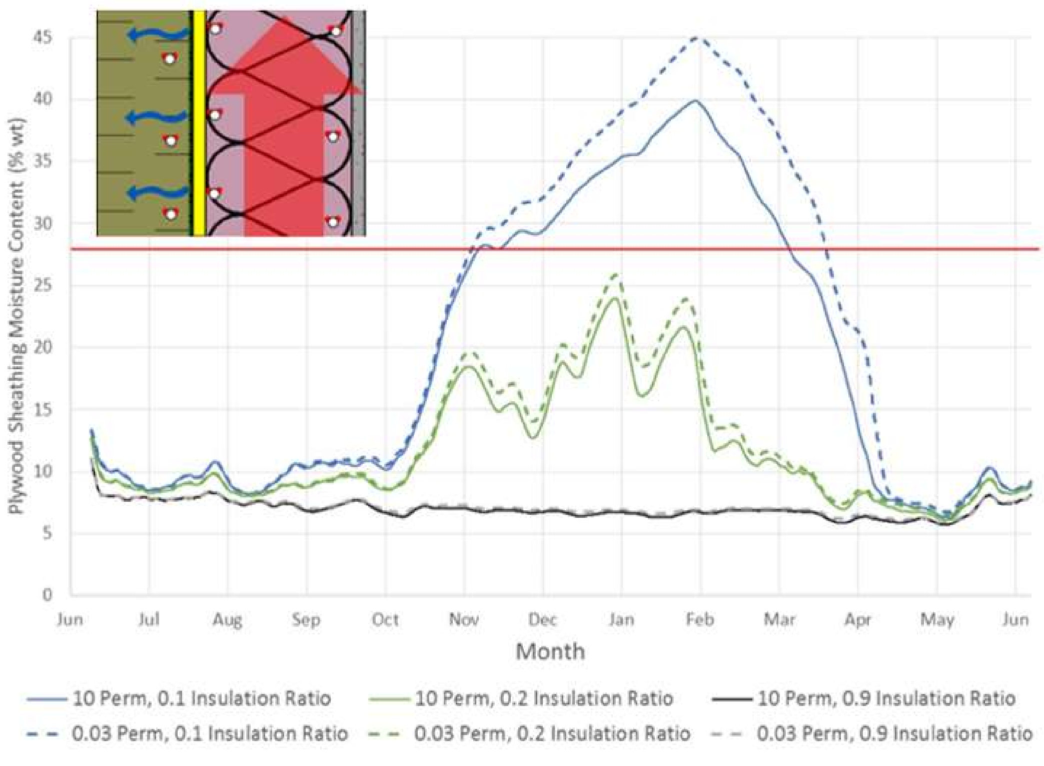


Figure 7: Example Impact of Insulation Ratio vs. Sheathing Membrane Vapour Permeance on Plywood Sheathing Moisture Content for Edmonton, AB

1 Lee, I., Roppel, P., Lawton, M., Ferreira, P. *Design Limits for Framed Wall Assemblies Dependent on Material Choices for Sheathing Membranes and Exterior Insulation*, Morrison Hershfield 2019

2 Straube, J. *Controlling Cold-Weather Condensation Using Insulation*, Building Science Digest 163, buildingscience.com, 2011

So, what is the correct ratio? A common, “old-school rule of thumb” has been ⅓ of the total R-value on the interior and ⅔ on the exterior. However, modern analysis demonstrates that this tends to be very conservative and often un-necessary in Canadian climates.

It is noted that the National Building Code has a table of insulation ratio values in Explanatory Note A9.25.5.2. These values were presented as part of initial housing research work conducted in the late 1980’s and early 1990’s at the National Research Council, with specific limited boundaries for interior and exterior climate and occupancy conditions. Subsequent research and modern hygrothermal modelling demonstrate that those values are conservative and may not apply to all areas of Canada due to the assumed climate and occupancy conditions of that early research.

Achieving a broad range of insulation Ratios increases design flexibility while still respecting building physics and the realities of the Canadian climate. Table 1 illustrates insulation ratios that go beyond current Code minimums (as referenced in the Explanatory Note A9.25.5.2) and represents current best practice in design[1,2].

The Ratios assume no interior vapour control layer and allow for any type of exterior insulation and sheathing. The Ratios allow for the temperature of the sheathing to be kept reliably above the indoor dew point temperature, which lowers the risks of condensation on the interior side of the sheathing.

The Insulation Ratio is expressed as a percentage using the following formula:

$$Ratio\ (\%) = \frac{Exterior\ nominal\ R\text{-}value}{Total\ nominal\ R\text{-}value}\ x\ 100$$

Table 1: Recommended Ratio of Exterior Thermal Resistance-to-Total Thermal Resistance to Limit Condensation Risk in a Split-Insulated Assembly

Average Winter Temperature Low (°C)	Average Indoor Wintertime Relative Humidity @20°C (RH%)				
	20% RH	30% RH	40% RH	50% RH	60% RH
0 °C	0%	12%	32%	47%	60%
-10 °C	23%	40%	54%	64%	73%
-20 °C	41%	55%	65%	73%	80%
-30 °C	53%	64%	72%	78%	84%
-40 °C	66%	70%	76%	82%	86%

It is important to note that the temperature reference is the average winter temperature low, not the NBC Appendix C2 January design temperature[2]. The average winter low temperature is the average of the monthly low temperature averages for each of December, January, and February. If a more conservative selection is desired then a colder temperature could be selected.

As an example, if your average winter low temperature was -20°C, and your average indoor RH during that same winter period was 30% RH (@20°C), then the Ratio of exterior R-value-to-Total R-value would be 55% or higher, to limit the risk of condensation. In other words, 55% or more of your total R-value would need to be from the sheathing outwards.

It is also important to understand that the Code and good design practice is focused on *limiting* the risks with condensation not completely eliminating condensation. Many common building materials can provide excellent durability when exposed to minimal amounts of condensation. Their ability to absorb and release these small amounts does not affect their long-term acceptable performance. However, if the material at the location of the sheathing is not able to absorb and release moisture then there may be a greater risk as any condensation that may occur could simply form on the surface and then drop to the bottom of the cavity.