[redacted]

No. 014

RDH Technical Bulletin

Net-Zero Design and Feasibility for Residential Buildings in the North

By Robin Urquhart, MBSc, CEA, and Graham Finch, P.Eng, MASc

The Net-Zero Challenge in the North

The unprecedented challenges presented by climate change have propelled governments to introduce new legislation aimed at greatly reducing energy and carbon usage in the building sector. In an effort to mitigate the effects of climate change, the Government of Canada has committed to net-zero emissions by 2050. But what does "net zero" actually mean? And how do we design residential buildings for it under the unique conditions in northern Canada and Alaska?

This bulletin describes a five-step approach used by RDH Building Science for designing residential buildings to achieve net-zero performance in the North. This approach is not intended to revolutionize the way we design buildings, but rather to use existing methodology and technology to build higher-performance buildings. This goal can be attained by modifying the design process and selecting more ambitious performance targets, as demonstrated with a case study example in this bulletin. The approach is broad enough that it can apply to any project. Net-zero performance is always possible, even in the challenging conditions of the North, but achieving this performance requires up-front, intelligent design.

The Meaning of Net Zero

"Net zero" is a nebulous term used across all industries and sectors. In the context of the built environment, net zero is classified into two groups: *net-zero energy* and *net-zero carbon*.

Net-zero energy

Net-zero energy means a building produces at least as much energy as it uses on an annual basis through renewable energy generation. A building is considered net-zero energy ready if the energy requirements for operation of the building are below a certain threshold (set by the energy code used for the design) such that a reasonably sized renewable energy generation system (solar, wind, geothermal) could offset the energy usage.

Energy is usually measured in Gigajoules (GJ) and includes all fuel types, not just electricity. The units of all fuel types are converted to GJ to allow the addition of energy sources and make results more comparable.

Net-zero carbon

Net-zero carbon means a building negates the amount of greenhouse gas (GHG) emissions resulting from various phases of its existence. The application of the word "carbon" can be a little misleading. In this context, carbon refers to carbon dioxide equivalent (C02e) and is used to quantify the total GHG emissions. The four major greenhouse gases—carbon dioxide, methane, nitrous oxide, and water vapour—have varying potency and longevity. For each gas other than carbon dioxide, certain factors are used to convert the effect of the gas into a carbon dioxide equivalent to allow for easier calculations and comparisons.

Other terms falling into the net-zero carbon camp include carbon neutral, net-zero operational carbon, net-zero emissions, and zero-carbon building. All these terms refer to elements of net-zero carbon design and depend on the context in which they are used. There is no hard and fast definition of net-zero carbon. Therefore, it is important to ensure that the definition used for a project is provided up-front in any phase of design development.

The metric for net-zero carbon is tonnes of carbon dioxide equivalent (tC02e).

Design Challenges in the North

The definition of “the North” is also context dependent. There is no agreed-upon definition among all disciplines. In the building science context, we define the North in terms of heating degree days (HDD). Any region that is greater than 5000 HDD qualifies as the North. In terms of the Model National Building Code of Canada (NBC) 2020, the North refers to climate zones 7A, 7B, and 8. In terms of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the North refers to climate zones 7 and 8. By these definitions, over 90% of the land area in Canada and Alaska is considered the North. According to both the NBC 2020 and ASHRAE, the “Far North” means climate zone 8.

Any definition of the North creates some issues because it suggests a uniformity that is inaccurate. Regions within the North can have dramatically different climates, HDD, logistical considerations, energy sources, building requirements, costs, and capacity. The challenges associated with northern regions will be examined further below; however, it is important to note that every location is different and must be understood on its own terms as part of the design development process.

Any definition of the North creates some issues because it suggests a uniformity that is inaccurate. Regions within the North can have dramatically different climates, HDD, logistical considerations, energy sources, building requirements, costs, and capacity.

Although all sites for building projects are different, the North has some common and specific considerations associated with it. Table 1 summarizes these considerations and the challenges they present for designers.

TABLE 1 SPECIFIC CONSIDERATIONS AND CHALLENGES FOR NET-ZERO DESIGN IN THE NORTH	
SPECIFIC CONSIDERATIONS	CHALLENGES
Site conditions 	• The presence of permafrost often requires buildings to be elevated, which restricts the foundation and floor assembly options. • Geographic constraints may impact cost, design choices, and project decision-making.

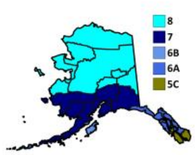
TABLE 1 SPECIFIC CONSIDERATIONS AND CHALLENGES FOR NET-ZERO DESIGN IN THE NORTH	
SPECIFIC CONSIDERATIONS	CHALLENGES
Transportation 	• Transportation may be seasonally constrained (winter roads, sealifts, barging, etc.). • Material options may be limited by transportation, especially for communities not connected by road. • Transportation options in the North can be more expensive.
Practical limitations 	• Many remote areas may lack a trained or scalable labour force. • Local construction equipment, materials, and fuel may be limited. • Some forms of technology, such as heat pumps and heat recovery ventilation (HRV) systems, have cold weather limitations and may not be suitable for all climates.
Building season  	• Climate zones are broad, incorporating large variations in HDD. • Weather data locations are far apart. • Many material/product installation recommendations require temperatures around or above 0°C, which limits application timing. *Note: Canada climate zones shown are per NBC 2020; Alaska-only climate zones shown are per the International Energy Conservation Code (IECC) 2021.*
Building energy performance standards ENERGY STEPCODE BUILDING BEYOND THE STANDARD	• In Canada, the primary regulatory codes aiming for net-zero energy performance are the BC Step Code 2018, which applies to BC, and the National Building Code of Canada (NBC) 2020. Northern jurisdictions also often have energy efficient bylaws, standards, or best practice guides. While these do not necessarily aspire to net zero, they are useful or mandatory in setting the baseline energy efficiency. • In Alaska, the Division of Fire and Life Safety adopts codes statewide, allowing

TABLE 1 SPECIFIC CONSIDERATIONS AND CHALLENGES FOR NET-ZERO DESIGN IN THE NORTH	
SPECIFIC CONSIDERATIONS	CHALLENGES
	the boroughs and municipalities to be more restrictive by adopting additional requirements if they choose. Currently there is no statewide energy code in Alaska.
Energy production capacity  *Photo by Michael Ross*	• Electrical grids are often isolated and cannot be used to offset energy/emissions by providing energy to other industries/buildings. • The local utility corporation may limit the uninterrupted power supply into the grid system. • Seasonal demand and supply are inverse because of cold temperatures, reduced sunlight during the coldest months of the year, and higher-occupancy enclosure loads (plugs, lighting, domestic hot water, etc.).
Construction costs 	• Construction costs in the North are generally higher than in southern locations, which accounts for both increased labour and material rates. It is common industry practice to adjust prices for northern regions with location costing factors.

A Five-Step Approach to Net-Zero Design

A simple and straightforward five-step approach to net-zero energy and carbon residential design is outlined in Figure 1. RDH regularly uses this approach for a variety of project types.

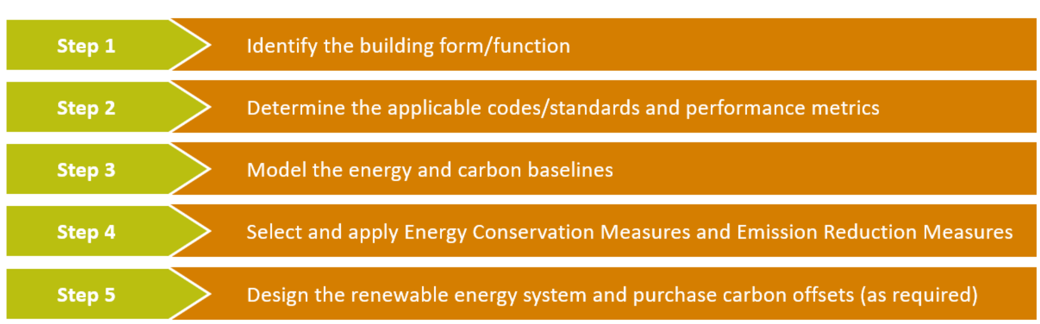


Figure 1: A five-step approach to net-zero energy and carbon design (adapted from Urquhart 2022).

Step 1: Identify the building form and function

It all begins with a building, or the concept of a building. The building type and function are based on the building's end use and are usually determined by the client. Once the building type and function have been identified, design can begin. At this stage, for a high-performance building in the North, the driving factors for energy efficiency are the massing (including the shape, size, and form of the building) and the fenestration to door/window ratio (FDWR).

Articulations in the building enclosure impact the building's energy efficiency because they increase the surface area through which heat may be lost to the outdoors. To assess this impact, the articulations can be expressed as a form factor, which is the total enclosure area divided by the gross floor area. A common form factor range is anywhere from 2 to 4.

RDH building scientists modelled a multi-unit residential building (MURB) in four climate zones in Canada (Finch et al. 2020). The results showed that, with all other factors staying the same, an increase in the form factor from 2.5 to 3.5 can almost double the energy usage in the coldest climates (see Figure 2).

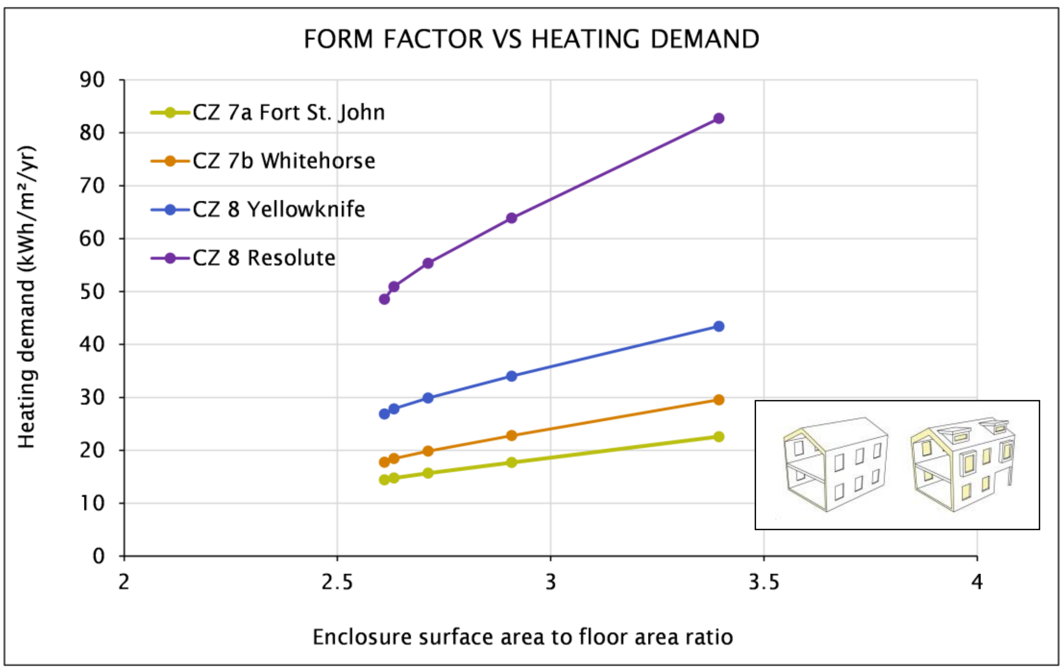


Figure 2: Effect of an increase in the form factor on heating demand in four different climate zones (CZs) in Canada (adapted from Finch et al. 2020).

Similarly, an increase in FDWR and orientation can significantly increase energy usage. In the same study, the researchers performed an analysis using a simple single-family dwelling (SFD) housing archetype in the same four Northern cities. The only variant was the FDWR of a high-performance, triple-glazed window (U-0.12, USI-0.69) with a high R-value wall assembly (Reff-80) over a range of typical SFD FDWRs. The results are shown in Figure 3, where each dot represents the addition of a 1.93 m × 1.5 m window on either the south or east/west façade as indicated. For example, the increase in window-to-wall ratio delineated by the orange box is a result of adding windows to the south façade. The general trend is

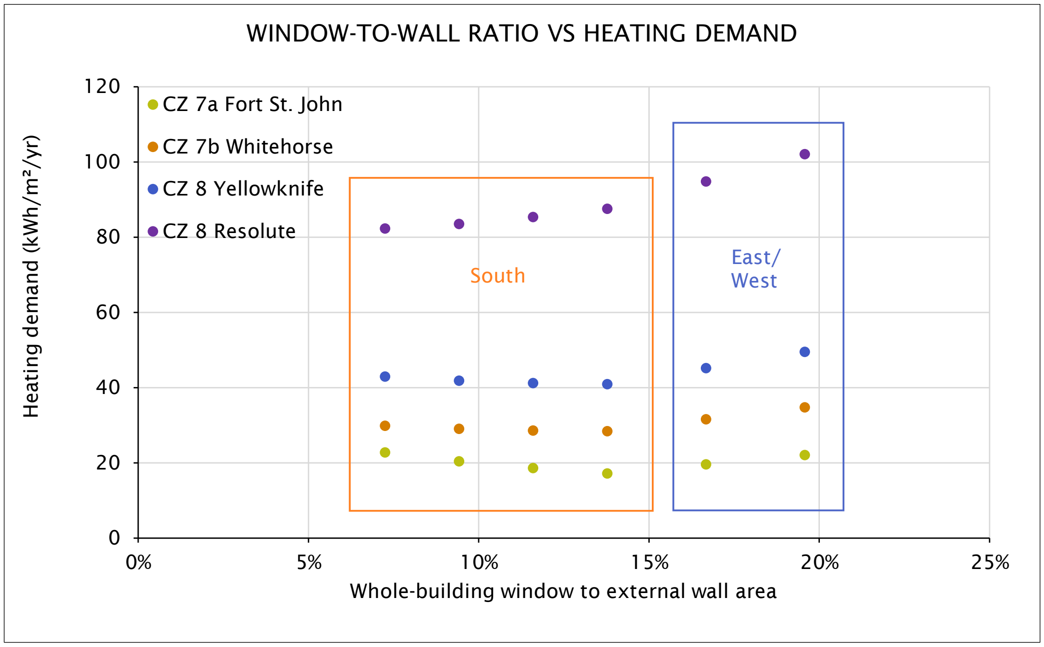


Figure 3: Effect of an increase in FDWR and orientation on heating demand in four different climate zones (CZs) in Canada (adapted from Finch et al. 2020).

that increasing the FDWR ratio on the south elevation reduces heating demand in this archetype. However, in latitudes as far north as Resolute, where very little solar radiation is available in the winter months, a house with no windows would be optimal from an energy efficiency standpoint—though not practical.

The study also showed that in climate zones up to 9000 HDD, southern exposure windows with a reasonable solar heat gain coefficient (SHGC), and depending on local climate conditions, are net-energy positive on an annual basis. This means the windows provide more energy than they lose over the calendar year. Windows on other elevations typically result in annual energy losses. The threshold for FDWR was roughly 15% as modelled by RDH in its Northern window study (RDH Building Science Inc. 2016). For climate zones above 9000 HDD, windows and doors on any orientation are net-energy negative.

Step 2: Determine the applicable codes/standards and performance metrics

In Step 2, designers determine the applicable codes or standards and performance metrics that will be applied to the project. Performance criteria in energy codes can assist with the design of net-zero energy and net-zero carbon buildings. Currently, two main reference codes apply in the Canadian North: the National Energy Code for Buildings (NECB) 2020 and the British Columbia Energy Step Code 2018 (which is legislated for BC but is useful across all jurisdictions). The NECB reference building provides a benchmark upon which to base the design. Designers may choose an energy reduction over the NECB reference building. While there is no specific guidance on what reduction percentage approaches net-zero design, a reduction of 50% is in line with net-zero reductions in other codes (BC Energy Step Code 2018, NBC 2020).

The NBC 2020 contains an energy performance compliance pathway similar to the tiered system in the BC Step Code. The metrics in Tier 5 of the NBC can be considered to be approaching net-zero ready design.

In Alaska, the Division of Fire and Life Safety adopts codes statewide, allowing the boroughs and municipalities to be more restrictive by adopting additional requirements if they choose. The state building code in Alaska is the International Building Code (2021). The Alaska Housing Finance Corporation adopted the International Residential Code for housing that receives state funding with an additional requirement to meet the Alaska State Building Energy Efficiency Standard (BEES). BEES references targets in the International Energy Conservation Code (IECC); however, the highest tier of the IECC is not considered approaching net-zero design. To date, Alaska has not adopted an energy code for buildings. However, there is nothing stopping designers and builders in Alaska from referencing the Canadian codes, which have proven effective for the same climate zones.

The Passive House Institute (PHI) and Phius also provide high-performance metrics that may be useful for designing net-zero energy buildings.

Step 3: Model the energy and carbon baselines

In Step 3, energy and carbon modelling are performed to assess the building's baseline energy and carbon performance.

Energy modelling

All performance-based pathways for energy codes require energy modelling, and the codes reference specific guidelines for energy modelling. In some cases, the energy code has energy modelling guidelines embedded in the code itself; in other cases, the code will reference a separate energy modelling guideline. The energy modelling guidelines specify the inputs and calculation methodology for the design of the energy model per the energy code being used.

The energy requirements may be a reduction of energy usage compared to the reference code building or prescriptive energy usage values. In most cases, the prescriptive energy metrics are some combination of thermal energy demand intensity (TEDI), mechanical energy use intensity (MEUI), and total energy use intensity (TEUI). In many cases, a maximum air leakage value measured in air changes per hour (ACH) must also be met.

Carbon modelling

Similar to energy modelling, a carbon model provides a baseline (as designed) understanding of the C02e emissions associated with the building. The standard method for modelling carbon intensity is a life cycle assessment (LCA). An LCA is a form of environmental analysis that assesses the potential C02e emissions resulting from the construction, use, and eventual disposal of the building. Figure 4 identifies the key factors in each stage of a building's life cycle that contribute to C02e emissions.

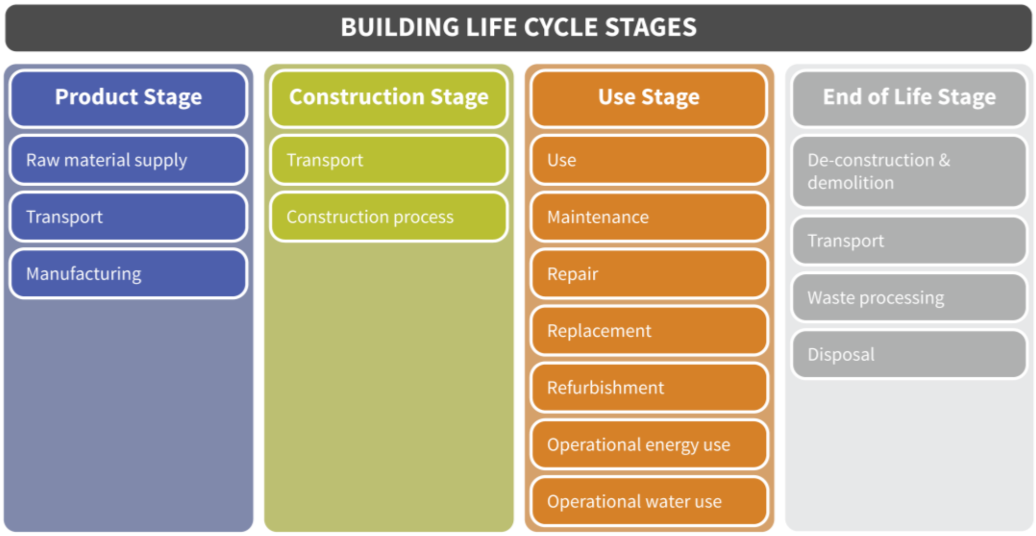


Figure 4: Key factors that contribute to C02e emissions in each stage of a building's life cycle.

Step 4: Select and apply appropriate energy conservation measures and emission reduction measures

The baseline energy and carbon models provide the designer with a starting point for increasing energy performance and carbon usage of the building. The relationship between energy conservation and carbon intensity is dynamic. Increasing insulation may reduce the operational energy requirements but may increase the emissions resulting from increased material usage. Therefore, an iterative approach is required to optimize the emissions associated with operational energy use and the emissions associated with the materials and components of the building. This iterative approach is applied in Step 4 by selecting and applying energy conservation measures (ECMs) and emission reduction measures (ERMs).

In general, selecting lower embodied energy materials will work toward optimizing the performance of the building as a whole; however, the appropriateness of an ECM or ERM depends on four critical factors: energy performance, carbon intensity, constructability, and cost (see Figure 5). Constructability includes considerations such as material procurement and transportation along with the technology and skills required for installation.

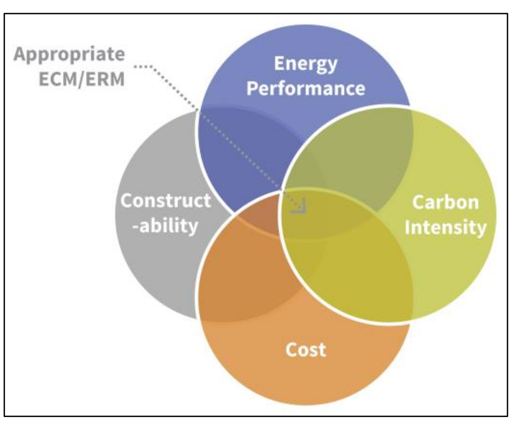


Figure 5: The four critical factors that determine the appropriate ECMs and ERMs to reach high-performance targets (adapted from Urquhart 2022).

In the North, ECMs and ERMs are constrained by the challenges and considerations endemic to the region. RDH conducted extensive research across manufacturers, trades, designers, and as-built construction in the North to develop the upper threshold for ECMs in the North (Finch et al. 2020). Aside from cost, the researchers encountered limits in terms of constructability and technology. Findings from this study and other project work are summarized in Table 2, which provides the upper threshold for construction in the North in terms of practicality, cost, and performance of different building components.

TABLE 2
HIGHEST-PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS

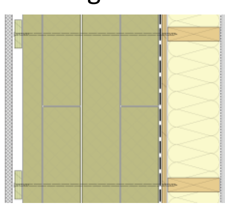
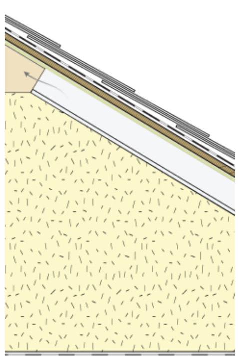
COMPONENT	PERFORMANCE	DESCRIPTION/EXAMPLE
Building Enclosure		
Above-ground wall 	R_{eff}-80 ft^2-hr-^{o}F/Btu (RSI-14.1 m^2-K/W)	This maximum recommended effective R-value is based on practical considerations for construction. It can be constructed in many different ways and would most simply be a 2 × 6 split-insulated wall with approximately 14” of exterior insulation attached with long screws or could alternately be a deep double stud wall system. This is the upper recommended limit for wall R-value as more exterior insulation would be practically difficult to build and deep framed walls become very thick and more challenging to effectively insulate with fibrous fill in these large of cavities.
Roof 	R_{eff}-100 ft^2-hr-°F/Btu (RSI-17.6 m^2-K/W)	This maximum recommended effective R-value is based on the practical depth for insulation within an attic assembly and typical roof slope for a northern house (above or below the tree line) to effectively manage snow and wind.

TABLE 2
HIGHEST-PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS

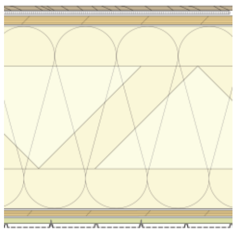
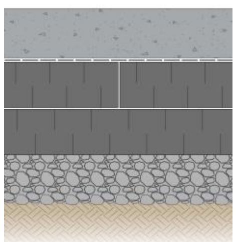
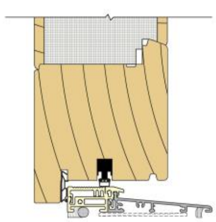
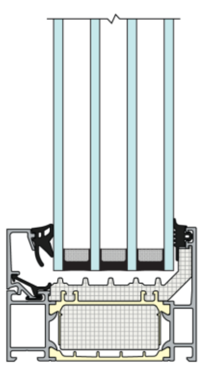
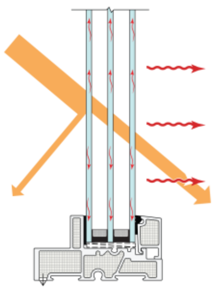
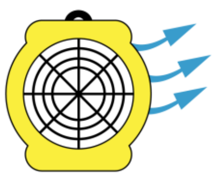
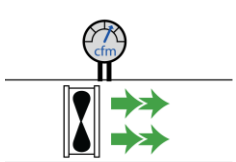
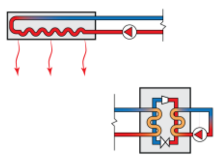
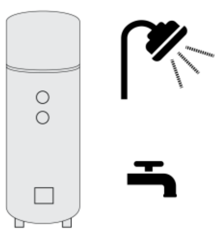
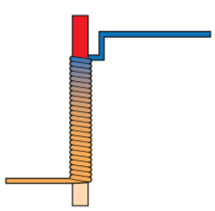
COMPONENT	PERFORMANCE	DESCRIPTION/EXAMPLE
Exposed floor 	R_{eff}-80 ft^2-hr-°F/Btu (RSI-14.1 m^2-K/W)	This maximum recommended effective R-value is based on practical maximum depths of floor joists/trusses filled with batt or blown fibrous insulation or the use of exterior rigid insulation similar to the wall system.
Slab on grade (non-permafrost areas) 	R_{eff}-40 ft^2-hr-°F/Btu (RSI-7.0 m^2-K/W)	This maximum recommended effective R-value is based on total heat loss through a ground-bearing assembly and practical thickness of foam insulation.
Door 	R-8 ft^2-hr-°F/Btu (RSI-1.41 m^2-K/W)	This is a practical performance limit based on the available insulated door products currently on the market.
Window 	U-0.12 Btu/ ft^2-hr-°F (USI-0.69 W/ m^2-K)	This is a practical performance limit based on the available high-performance frames with krypton-filled quad-glazing IGUs and triple low-e coatings currently on the market.

TABLE 2
HIGHEST-PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS

COMPONENT	PERFORMANCE	DESCRIPTION/EXAMPLE
Window SHGC[1] 	0.40	This relatively high balanced SHGC is typically used in Passive House designs to maximize passive solar heat gains. Higher SHGC products are available with fewer low-e coatings, though at the expense of a higher IGU U-value.
Airtightness 	Single-family detached: 0.30 ACH50 MURB & multi-plexes: 0.15 ACH50	The 0.15 ACH50 performance is 4× tighter than the Passive House requirement and has been achieved on several new construction projects using an exterior sealed sheathing air barrier strategy for walls/roof.
Ventilation		
HRV efficiency 	90%	This efficiency is the highest tested efficiency for a cold climate HRV that does not require preheat or defrost cycles based on a dual core system. Note that higher efficiency (e.g., 95%) units require a significant amount of pre-heat energy or defrost control.
Ventilation rate corridor, MURB 	10 cfm/suite	This is the lowest recommended ventilation rate for corridors using a balanced ventilation approach, based on industry expertise.

1 SHGC refers to the overall solar heat gain coefficient for the glazing and window frame, whereas g-value, which is typically used in Passive House modelling, refers to the solar heat gain for the glazing only. A SHGC of 0.4 will roughly translate to a g-value of 0.5.

TABLE 2
HIGHEST-PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS

COMPONENT	PERFORMANCE	DESCRIPTION/EXAMPLE
Mechanical System		
Space heating system 	Cold climate air source heat pump, annual COP 1.5–2.1[2]	COP[3] depends on location due to differences in outdoor air temperature. Systems revert to electric resistance (COP 1.0) at a threshold low temperature.
Domestic hot water system 	CO_2 heat pump, annual COP 2.5–3.0	COP depends on location due to differences in outdoor air temperature.
Drain water heat recovery (DWHR) 	65%[4]	This is the maximum allowable DWHR efficiency in the HOT2000 modelling program, reflecting high- performance units.

Net-zero energy feasibility in the North

The spectrum of energy efficiency for a project is defined at one end by the baseline design (reference building) and at the other by the application of the practical limit ECMs. Keeping this spectrum in mind, RDH examined the feasibility of net-zero energy ready design in the North using the metrics provided by the BC Energy Step Code 2017/18 for three archetypes: single-family detached, MURB, and row house (Finch et al. 2020). The study showed that it is possible to meet the highest level of the BC Energy Step Code for most archetypes in most Northern climate zones. Subsequent updates to the BC Energy Step Code ensure that all archetypes in all Northern climate zones can reach the highest tier within the ECM thresholds presented in Table 2.

[2] Kegal, M., Sager, J., Thomas, M., Giguere, D., and Sunye, R. (2017): Performance Testing of Cold Climate Air Source Heat Pumps; 12th IEA Heat Pump Conference.
[3] COP stands for coefficient of performance and indicates the efficiency of the heat pump.
[4] Average efficiency based on the Passive House certified component database.

Carbon efficiency

In terms of ERMs, there are two areas to focus on: carbon intensity of materials and carbon intensity of energy sources. The LCA will help in identifying high-carbon intensity materials and serve as a starting point for choosing lower carbon intensity materials that still meet energy model requirements. As mentioned above, the relationship between material emissions and operational emissions is dynamic, and iterative modelling is required to optimize ERMs and ECMs. The second consideration for reducing emissions is the energy source used for building operation. The emissions associated with the source energy is usually referred to as an emissions factor.

In terms of ERMs, there are two areas to focus on: carbon intensity of materials and carbon intensity of energy sources.

Different fuel sources have different emissions factors. The emissions factor is expressed as grams of C02e per unit of fuel and reflects the greenhouse gas emissions associated with the production of energy from the fuel source. For example, electricity generated through the combustion of diesel has a higher emissions factor than electricity generated through solar panels or hydroelectric projects. In the North, heating plays a critical role in energy efficiency, and in tandem with reducing heating load, choosing a carbon-efficient heat energy source can significantly reduce overall project emissions.

Step 5: Design the renewable energy systems and purchase carbon offsets

Renewable energy generation

Renewable energy generation in the North is more complicated than in more densely populated areas owing to two key factors: the inverse relationship between generation potential and demand, and the lack of electrical grid connectivity.

An inverse relationship exists in the North between the renewable (solar and wind) energy generation potential and energy demand. In the winter, northern buildings require more energy than in the summer. The buildings require more heat and light, and occupants spend more time inside. At the same time, there is less solar radiation, which has two important consequences: it reduces energy capture from solar panels, and it lowers the differential heating of the land surface, which generates less wind. Conversely, in the summer, when energy demand is at its nadir, energy production potential is highest.

The inverse power relationship is complicated by the lack of grid connection in remote communities. In all remote Northern communities, the electricity is supplied from a standalone electrical grid. In connected grid communities, it is conceivable that the overproduction of energy in the summer could be used to offset winter energy requirements by sending energy down to manufacturing plants in the south or to meet energy demand throughout a large, connected grid. In standalone grid communities, there is nowhere for an over-production of energy to go.

If a renewable energy system is sized to meet the annual energy demands of the building, it will only produce too much energy in the summer and not enough in the winter. Usually, power corporations limit the amount of uninterrupted power generation in a standalone grid, so even local grid tie-in is often not an option. Research and technology for local energy storage systems is in its nascent stage, and an application for remote Northern communities is not in the foreseeable future.

Carbon offsets

Carbon offsets are a form of carbon credits that are used to fund projects designed to reduce the amount of C02e in the atmosphere. Examples of carbon offset projects include switching to renewable fuel sources and supporting reforestation. Offsets help to balance out the carbon usage in one location by reducing carbon in another location, resulting in a net-zero effect. A variety of providers offer carbon offsets, some of which are more reputable than others.

Currently it is not possible to design a net-zero carbon building in a remote Northern community that does not rely on carbon offset purchase. The lack of a connected grid system means that buildings cannot offset carbon usage (embodied and operational) through renewable energy electricity generation.

Carbon offsets help to balance out the carbon usage in one location by reducing carbon in another location, resulting in a net-zero effect.

Currently it is not possible to design a net-zero carbon building in a remote Northern community that does not rely on carbon offset purchase.

The cost of carbon ($/tC02e) is set by the carbon offset market. However, governments may institute a carbon shadow price to incentivize projects to minimize carbon offset purchases. For example, in 2022, the carbon shadow price set by the Treasury Board of Canada was $300/tC02e, whereas offsets could be purchased in the market for $4–20/tC02e. The increased shadow price is meant to reflect the increasing cost of carbon offsets and to recognize that this is a finite solution, beyond which meaningful carbon reduction will be required on the individual project level.

Case Study Building

The following case study of a net-zero energy ready building constructed in climate zone 7B demonstrates how the net-zero design approach described in this bulletin can be used to achieve net-zero performance in a cold climate.

The case study building, constructed in 2022–2023, is a 204 m^2 (2200 ft^2), 1.5-storey, single detached house located in Atlin, British Columbia (see Figure 6). The building meets the criteria for Step 5 of the BC Energy Step Code (2018) and is the northernmost Step 5 building in British Columbia.

Case study Step 1: massing and orientation

The case study building was oriented due south to take advantage of solar heat gain. The overall FDWR is 12% with a FDWR of 36% on the main south wall. The articulations were minimized to a single wing off the main volume at a 55˚ angle. The form factor for the building is 2.82. The roof overhang and canopies at the south and west elevations provide shading in the summer months (June–August) to avoid overheating and allow the sun to penetrate the building when it is at a lower angle (September–May).

Figure 6: The 204 m² (2200 ft²) case study home located in Atlin, BC.

Figure 7(a) and (b) depict the shading of these elevations at two different times of the year. A 5" thick monolithic slab-on-grade provides thermal mass to absorb solar energy during the day and radiate it back into the house throughout the dark hours.

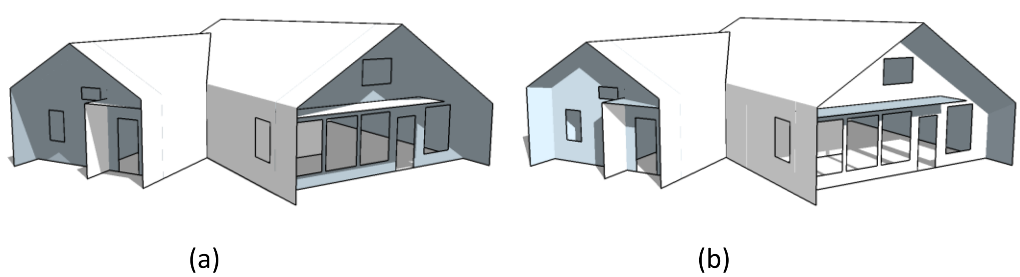


Figure 7: Shading analyses of the case study building located at 59.5780˚N, 133.6895˚W during two different times of the year: (a) on August 18, 2022, at 12:00 pm (UTC-7), and (b) on November 26, 2022, at 12:00 pm (UTC-7).

Case study Step 2: applicable codes/standards and performance metrics

Atlin, BC, according to Natural Resources Canada's Hot2000 Climate Map[5] (which references Teslin, YT, as the closest weather station), has 6874 HDD (see Figure 8). Therefore, the case study building is located in climate zone 7B (HDD 6000–7000).

Figure 8: Hot2000 climate map used to determine the HDD of the case study building in Atlin, BC (contains information licensed under the Open Government Licence – Canada).

The building conforms to Part 9 of the British Columbia Building Code 2015. The energy metrics in the BC Energy Step Code for Part 9 buildings are MEUI and TEDI. Table 3 shows the thresholds to meet Step 5 of the BC Energy Code standard for climate zone 7B.

TABLE 3
THRESHOLDS TO MEET STEP 5 REQUIREMENTS OF THE BC ENERGY STEP CODE IN CLIMATE ZONE 7B

BC Energy Code Step	Air Changes Per Hour (ACH)	MEUI	TEDI
5	≤ 1.0 ACH @ 50Pa	≤ 65 kWh/(m^2 – year)	≤ 50 kWh/(m^2 – year) or not less than 50% performance improvement over the EnerGuide Reference House

The BC Energy Step Code recommends Hot2000 as the modelling software for Step Code compliance for Part 9 buildings. Hot2000 has the EnerGuide reference house built into the software, which makes it much easier to compare the design model and the reference house than other types of modelling software.

Case study Step 3: energy and carbon baselines

The project brief for the case study building was net-zero energy ready. The overarching goal for the case study building was energy reduction and thermal resiliency. Based on the massing and other elements of the design from Step 1, a reference building energy model was created in Hot2000 per the Energuide Rating System V15.7.

[5] HOT2000 Climate Map: https://open.canada.ca/data/en/dataset/4672733b-bbb6-4299-a57f-f19ab475ac11

Low embodied carbon materials were selected when appropriate/available, but the carbon baseline of the building was not calculated.

Net-zero performance is always possible, even in the challenging conditions of the North, but achieving this performance requires up-front, intelligent design.

Case study Step 4: energy conservation measures

The design followed an enclosure-first approach sequence (depicted in Figure 9) and focused on enclosure thermal resistance (R-values) as the primary ECM. The optimal amount of insulation in the wall assembly was determined by iterations of the energy model (see Figure 10). Only building materials that are regularly stocked at the building suppliers in Whitehorse, YT (closest supplier to Atlin, BC) were selected to minimize construction delays and cost and to prove the net-zero buildability of the home in its remote location.

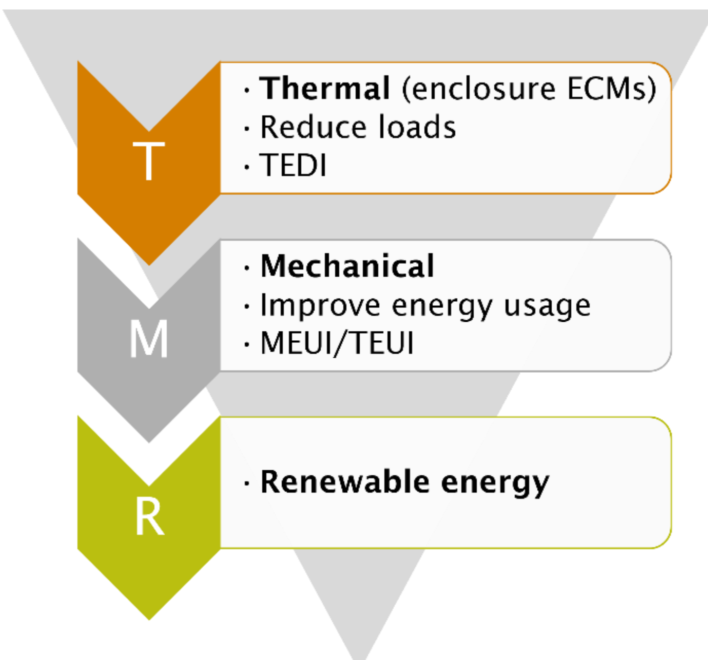


Figure 9: The sequence of the enclosure-first approach.

Transportation and other constraints were also considered but with one exception: the windows were ordered from Manitoba because the local manufacturer could not supply windows with the performance requirements for this design. All windows were fibreglass frame, triple-pane, and argon filled with double low-e coatings (see Figure 11). The south elevation windows had a USI of 0.90 and SHGC of 0.48, while other elevations had a USI of 0.79 and SHGC of 0.28.

Figure 10: Exterior insulation was installed over a water-resistant barrier (WRB) on the case study building. The WRB is the last line of defence to water penetration in the wall assembly.

Figure 11: The triple-glazed, double low-e coated windows installed in the case study building. The south elevation has SHGC 0.48 windows to maximize the solar heat gain, while other elevations have SHGC 0.28 windows.

The mechanical system focused on simplicity and ease of installation to avoid the necessity of specialty installers not located in the community. In-slab electric resistance heat was selected with wired-in (but not connected) electric baseboard for futureproofing in case any issues arose with the in-slab electric heat. A wood stove will be installed to improve thermal resilience of the building in case of power outages. A fully ducted energy recovery ventilator (ERV) was selected with listed energy recovery efficiencies of 85% in summer and 60% in winter (Figure 12). A conventional hot water heating system was selected with a uniform energy factor (UEF) of 0.91. All mechanical systems were selected based on availability, cost, proven performance in the North, availability of local parts for maintenance, and ease of installation.

Figure 12: The high-efficiency, fully ducted ERV installed in the case study home.

Through iterative modelling, the enclosure resistance values, including window performance and FDWR, were tweaked until the project design energy model met the BC Energy Code Step 5 criteria with a 20% margin to allow for design changes and updates. The selected design parameters of the building assemblies are summarized in Table 4.

Case study Step 5: renewable energy system

A renewable energy system was not designed for this building. Atlin, BC, is on a standalone electrical grid with a hydroelectric generating station. Transmission lines from the station to the project site were roughly 5 km, leading to almost no transmission losses. Installation of a solar array would not have been an environmentally friendly solution on this project because a source of renewable energy already exists without any additional material cost. While carbon was not considered in the project brief, it was clear that the carbon intensity would only increase through the installation of a solar array.

TABLE 4
DESIGN PARAMETERS OF THE CASE STUDY BUILDING ASSEMBLIES

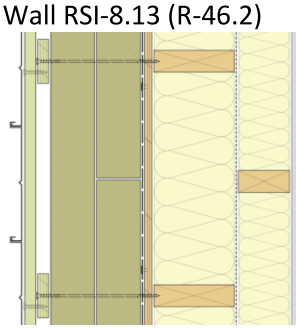
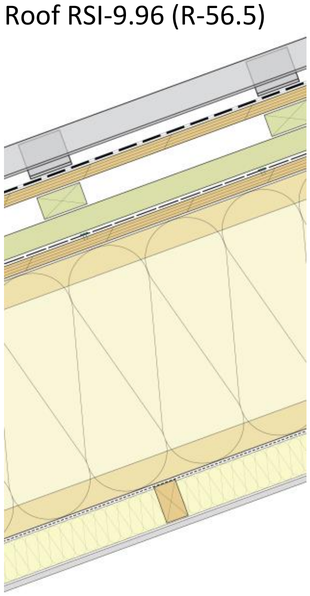
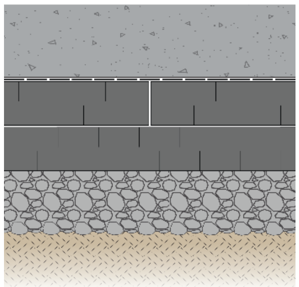
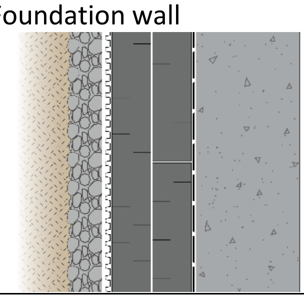
ASSEMBLY	DESCRIPTION
Wall RSI-8.13 (R-46.2) 	*Exterior to interior* - Cladding (standing seam metal or pine panelling) - 19 mm horizontal strapping - 38 mm vertical strapping - 152 mm Comfortboard 110 rigid mineral wool insulation - Tyvek (taped) (WRB) - 15.5 mm plywood sheathing - 140 mm wood stud with fibreglass batt infill - 6 mil polyethylene air barrier/vapour barrier (AB/VB) - 64 mm wood strapping with fibreglass batt infill - 13 mm gypsum wallboard
Roof RSI-9.96 (R-56.5) 	*Exterior to interior* - Roofing (standing seam metal) - Roofing underlayment (WRB) - 18.5 mm plywood sheathing - 38 mm horizontal strapping - 38 mm vertical strapping - Tyvek (taped) (WRB) - 406 mm TJIs with fibreglass batt (R40+R20) - 6 mil polyethylene (AB/VB) - 64 mm wood strapping with fibreglass batt infill - 13 mm gypsum wallboard
Floor RSI-4.78 (R-27.2)	*Exterior to interior* - 102 mm granular fill - 152 mm expanded polystyrene insulation - 15 mil polystyrene soil gas membrane (AB/VB) - 125 mm concrete slab

TABLE 4 DESIGN PARAMETERS OF THE CASE STUDY BUILDING ASSEMBLIES	
ASSEMBLY	DESCRIPTION
	- Floor finish
Foundation wall 	*Exterior to interior* - Granular backfill - Drainage mat with integrated filter fabric - Perforated drainpipe at footing - 152 mm expanded polystyrene insulation - Damp-proofing - 203 mm concrete foundation wall
Windows	Triple-pane, argon, double low-e, USI 0.9/SHGC 0.48 south, USI 0.79/SHGC 0.28 west, east, north, fibreglass frame
Doors	Steel skin, polyurethane core
FDWR	12%
Heat recovery	Energy recovery ventilator (85/60)
Domestic hot water	UEF 0.91
Space heating	Electric in-floor
Air changes per hour @ 50 Pa	1.0
Plug loads, lighting, etc.	Hot2000 default values
Occupancy	Hot2000 default values

Case study results

The case study building easily met the BC Energy Code Step 5 criteria for climate zone 7B. The important takeaway from this case study example is that there is nothing particularly special about the building. A baseline on which to design an energy efficient building was achieved by following the net-zero design approach and recommendations for northern climates, like maximizing solar heat gain, minimizing FDWR, and maintaining a relatively low form factor. Triple pane windows are the industry standard for new construction in northern jurisdictions and exterior insulation is also commonplace. Interior strapping is frequently used to achieve higher airtightness values with an interior air barrier approach while providing an added insulation benefit to the enclosure. The mechanical systems were readily available, off-the-shelf systems and were easy to install.

The airtightness of the building was tested at mid-construction and a thermographic analysis conducted to seal discontinuities in the air barrier. The final airtightness for the project was 0.62 ACH @ 50 Pa. The energy model was updated with the tested airtightness value and compared against the Energuide Reference House to assess compliance (Table 5).

TABLE 5
BC ENERGY CODE STEP 5 REQUIREMENTS VS. CASE STUDY AS-BUILT PROJECT PERFORMANCE

	AIR CHANGES PER HOUR (ACH)	MEUI	TEDI
BC Energy Code Step 5 requirements	≤ 1.0 ACH @ 50 Pa	≤ 65 kWh/(m^2 – year)	≤ 50 kWh/(m^2 – year) or not less than 50% performance improvement over the EnerGuide Reference House
Case study as-built performance	0.62 @ 50 Pa	44 kWh/(m^2 – year)	23 kWh/(m^2 – year), 70% performance improvement over EnerGuide Reference House

Conclusion

In all locations, but especially in the North, designers seeking net-zero building performance need to consider the building orientation and articulations, FDWR, available labour and skills, available materials, and logistical constraints. These considerations will influence the range of ECM and ERM options for the project. Designers can optimize the building performance by using an enclosure-first approach and selecting low-embodied energy materials and efficient mechanical systems. By using iterative energy modelling, they can refine the ECM/ERM options to arrive at a design that meets the energy requirements of the project.

Net-zero energy and carbon buildings in the North are very achievable in all climate zones using existing technology and standard industry practices. The most important aspect of net-zero energy buildings is the upfront design. Using a proven design approach and making intelligent design choices are keys to unlocking the net-zero potential in the North.

For additional information on this and other topics, please visit our website, rdh.com, or contact us at hello@learnbuildingscience.com.

References

- British Columbia Energy Step Code 2018. https://energystepcode.ca/
- Finch, G., Henderson, E., Wai, S., and Catania, E. 2020. Near-Net Zero Buildings in the North: Final Report. Revised April 21, 2020. https://www.rdh.com/resource/near-net-zero-buildings-in-the-north-final-report/
- National Energy Code for Buildings (NECB) 2020.
- RDH Building Science. 2016. Optimal Northern Wall Design Guidelines. Prepared by RDH for CMHC. Submitted May 26, 2016. https://www.rdh.com/resource/optimal-northern-wall-design-guidelines/

→ Urquhart, R. 2022. Net-Zero Energy and Carbon Building Design: Feasibility in Northern Canada and Alaska. Presented November 16, 2022. https://www.rdh.com/resource/net-zero-energy-and-carbon-building-design-feasibility-in-northern-canada-and-alaska/

Additional Resources

- Building A Legacy North website: https://www.communityenergy.ca/bal-north/
- Climate Change Resilience for Buildings, prepared by RDH Building Science for BC Housing, May 2021: https://www.rdh.com/resource/climate-change-resilience-for-buildings/
- Cold Climate Housing Research Center (CCHRC), Fairbanks, AK, website: http://cchrc.org/
- Considering Carbon in the Design of Building Enclosures, Building Science Live presentation recorded on October 15, 2022, by Graham Finch and Malin Ek:

  https://www.rdh.com/resource/considering-carbon-in-the-design-of-building-enclosures-building-science-live-presentation/
- Energy Efficient Housing Retrofit Guide for Yukon, updated March 3, 2022: https://yukon.ca/en/energy-efficient-housing-retrofits-yukon-guide
- Energy Efficient Northern Housing Guide – Cost Optimized, prepared by RDH Building Science for Natural Resources Canada: https://www.rdh.com/resource/energy-efficient-northern-housing-guide-cost-optimized/
- Energy Efficient Northern Housing Guide – Energy Optimized, prepared by RDH Building Science for Natural Resources Canada: https://www.rdh.com/resource/energy-efficient-northern-housing-guide-energy-optimized/
- Illustrated Guide for Northern Housing Retrofits, prepared by RDH Building Science for Natural Resources Canada: https://www.rdh.com/resource/illustrated-guide-for-northern-housing-retrofits/