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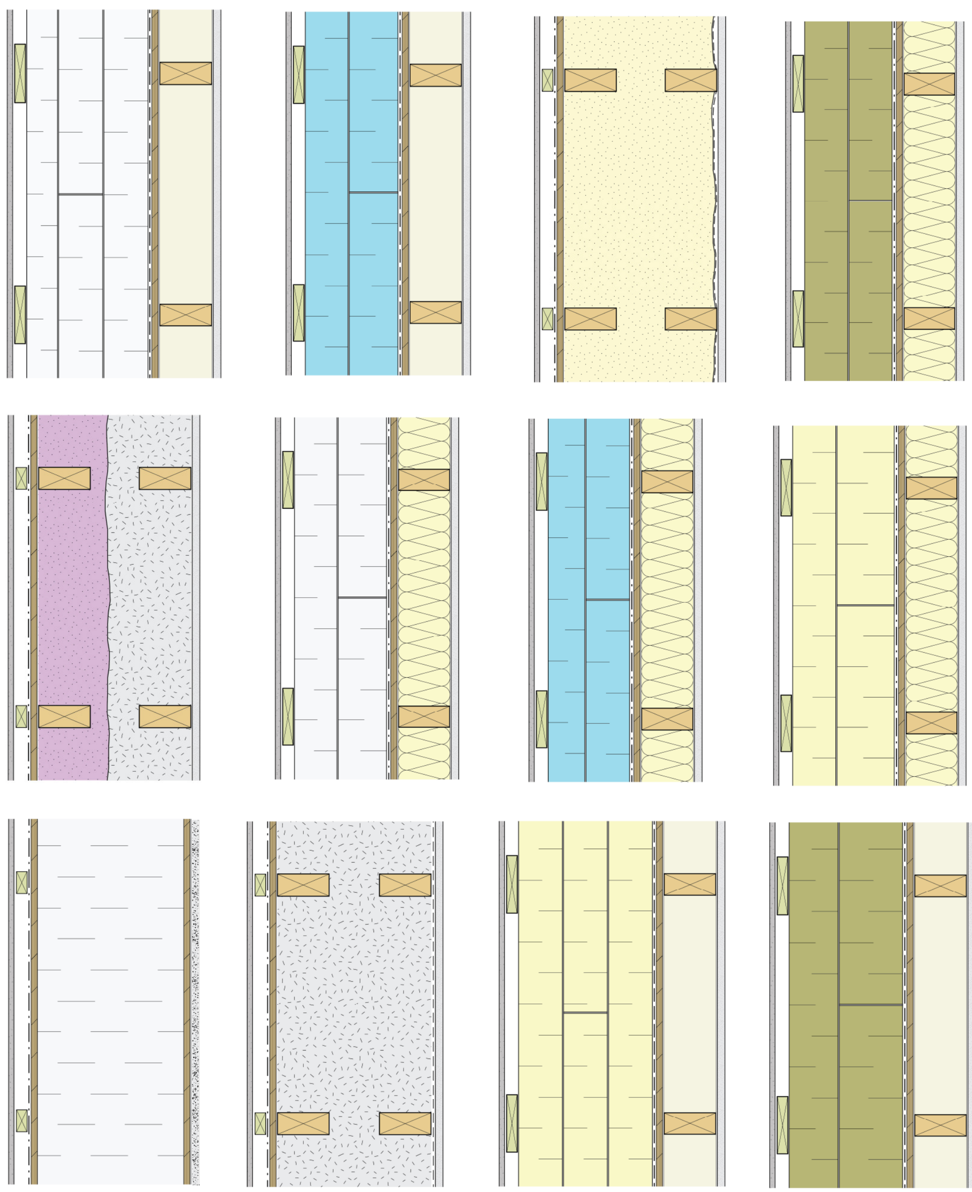
Optimal Northern Wall Design Guidelines | Project 8017.300



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Executive Summary

Buildings in the North require a novel approach compared to standard construction in the more temperate regions of Canada. Extreme cold temperatures, intense winds, permafrost, and limited supply chains for both material, resources, and labour, present unique challenges. The goal of this document is to provide designers, builders, and owners with guidance on energy efficient, comfortable, and cost-effective wall designs in the Yukon, Northwest Territories, and Nunavut.

A number of pre-requisites for the wall assembly were set, such as requiring rain-screen cladding, structural wood framing, and continuous air barrier system. The thermal resistance of the assemblies was designed to ensure a minimum R-40 effective. This value was determined as being optimal over the life-cycle of wall assemblies in the North. Once the pre-requisites were met, the wall assemblies were then evaluated on non-critical criteria. These criteria were hygrothermal durability, thermal efficiency, constructability, cost, and resource efficiency.

Analysis of the results indicate that a 2x4 wood-framed split insulated wall assembly with either 5" of exterior extruded polystyrene (XPS) or 6.5" of expanded polystyrene insulation (EPS) and ~R-13 fiberglass batt meets the required hygrothermal performance, is readily buildable by local contractors without any specialized trades or skillsets, and optimizes Northern Canadian material costs with labour costs. The use of 6" of rigid mineral wool (8 pcf density) as exterior insulation in lieu of EPS or XPS is a suitable alternate in terms of buildability and hygrothermal performance in this assembly though is slightly more expensive in the North due to shipping of this heavier rigid insulation type to remote locations. Polyiso insulation is not currently recommended for use as exterior insulation within the far North based on this analysis due to its comparatively poor performance under cold temperatures. The least expensive wall to build in all regions of the North is a 2x4 double stud wall with ~14" of fiberglass batt (3 layers, 2x ~R-13 and 1x ~R-28) though is more at risk for condensation and moisture damage from a hygrothermal standpoint than a split or exterior insulated wall.

Introduction

The population of Canada's North is increasing significantly, creating a need for new housing and other facilities. Rising land costs and energy prices have negatively impacted housing affordability. Further, climate action goals continue to push the envelope in energy efficient building design.

Canada's North presents unique design conditions due to several factors. The high winds in regions above treeline, presence of permafrost, material supply and transportation considerations, extreme cold temperatures and energy costs are some of the larger considerations to take into account when designing and building in the North.

The goal of this document is to provide designers, builders, and owners with guidance on energy efficient, comfortable, and cost-effective wall designs in the Yukon, Northwest Territories, and Nunavut. In particular, this document covers the following wall-related design considerations:

- → Hygrothermal Durability
- → Thermal performance
- → Constructability
- → Cost
- → Resource Efficiency

It is important to note that the building enclosure is only one part of a very complex building system. Considerations must be made for the connection and details between different enclosure assemblies and interaction of the various building components, including the mechanical and ventilation systems, the exterior and interior environments, and the occupant use and behaviour. Consequently, this wall design guide must be considered as only one component of the building system.

This work is based on a combination of interviews with builders, material suppliers, and developers who operate in Canada's North, as well as a parametric analysis performed using hygrothermal and thermal simulations to assess the thermal resistance and moisture performance of wall assemblies. Cost analyses, including shipping and crating fees, and constructability assessments are also considered as part of this work. While this guide focuses on design recommendations and associated financial implications, a background on the technical analysis is provided in the attached appendices.

Current Practices in the North

The primary objective is to identify an ideal highly insulated exterior wall assembly for the North. Such a wall would be applicable for both residential and low-rise commercial applications. As the Canadian North represents a very large area with varying ecologies, municipal plans, transportation realities, climates and topographies, two building regions were considered as part of this work:

→ Remote areas where the building material is likely shipped by boat, barge, or airplane. These areas tend to be located above the tree line and are situated on permafrost. These areas are characterized by very high labour rates and significant infrastructure limitations.

→ Major communities, where building materials is most likely to be shipped by truck via roads or ice-roads. These buildings may be located on permafrost as well, but are typically situated below the tree line.

The stark difference between these two regions requires separate analysis, as each possesses different parameters for their design: light-weight, low-bulk materials for the remote areas, whereas these are of lesser concern for population centres below the tree line, where costs are of greater concern due to increased populations.

To better encompass the range of variability in Northern Housing, this research will focus on select population centers that provide reasonable limits to these ranges. For high population centres that fall below the tree line, Whitehorse, Yukon, and Yellowknife, Northwest Territories, will be used. For remote locations, Resolute Bay, Nunavut, was chosen.

Typical Wall Assemblies

It has long been known that construction practices in the temperate regions of Canada do not directly translate into successes in the North. Consequently, many unique approaches towards building walls in the North have been developed as a response to specific challenges and needs. While 2x4 and 2x6 framed walls with interior vapour barriers have known a degree of success, they are equally renowned for significant failures caused by air leakage. When considered with their thermal inefficiencies, operating and heating buildings comes at significant cost to owners. Consequently, many alternatives for high R-value walls have been considered and built. While numerous different wall assemblies are being trialed, many of these wall assemblies have not been fully analyzed in this manner for the North. Double-stud walls are typical assemblies found in more urban areas, exterior insulation is common for commercial buildings and many single family home builders install interior insulation to add extra thermal resistance to the wall assembly to meet local code or bylaw insulation requirements and protect the polyethylene air/vapour barrier from damage, as shown in Figure 1 and Figure 2.

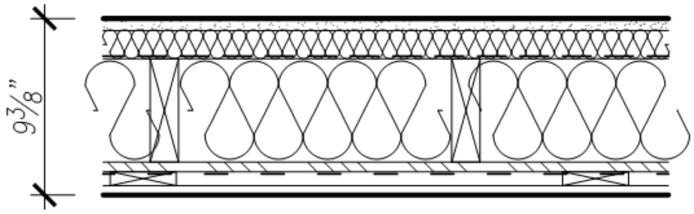


Figure 1 – Typical 2x6 wood framed wall section with 1.5" of interior semi-rigid insulation providing approximately R-24 effective considering 1.5" of interior mineral wool (R-6) and R-22 fiberglass batts (NBC 9.36 calculations)

Figure 2 – Photograph of a 2x6 wood frame wall in Yellowknife with batt insulation and polyethylene and interior 2x2 cross strapping for interior insulation (Photo: Larry Jones)

Building Code Requirements

The Canadian territories have adopted the National Building Code (NBC) with some modifications and additions. The 2010 NBC was revised in 2012 to include new energy efficiency provisions for Part 9 buildings (Section 9.36), which include specific requirements for the thermal performance of windows. These requirements have already been adopted in the Yukon, and are being considered in the Northwest Territories and Nunavut. Under this code, the minimum required R-value for a Part 9 house with a heat recovery ventilator (HRV) is an effective RSI-3.08 (R-17.4) and without an HRV is an effective RSI-3.85 (R-21.9). For larger Part 3 buildings under the 2011 National Energy Code for Buildings (NECB), the minimum effective R-value for walls in the North (Climate Zone 8) is RSI-5.45 (R-31.0).

Yukon

According to the NRC model code adoption website, NBC 9.36 energy performance requirements have been adopted in the Yukon. The Whitehorse building department website refers builders to the New Green Building Standards which require and EnerGuide Rating System label of 82 or better for all new homes. There is no formal reference to NBC 9.36.

Northwest Territories

According to the NRC model code adoption website, the Northwest Territories have not yet adopted NBC 9.36. The City of Yellowknife however regulates the energy performance of buildings by bylaw, and requires all single family and two family residential buildings to be designed and built to and EnerGuide for New Houses rating of 80.

There are no building code inspections outside of Yellowknife where the Office of the Fire Marshall simply advises builders to follow the Code.

Nunavut

According to the NRC model code adoption website, Nunavut has not yet adopted any part of the National Building Code, however efforts are underway to develop building regulations modeled on the National Code.

Beyond Minimum Code

Owing to the extreme challenging environment, many buildings in the North are built beyond minimum code requirements. This may be handled through local bylaws, the EnerGuide program, or in the case of Nunavut and the Northwest Territories through "Good Building Practices" publications. These insulation R-value targets are summarized in Table 1. As shown, design targets of low to mid R-20 effective R-values (above R-28 nominal) are typical baseline performance target for Northern wall assemblies.

Table 1 – Summary of Minimum Insulation R-value Targets for Buildings in Canada's North

Guideline, Bylaw or Green Standard	Walls: Minimum Insulation R-value (IP)	Roof – Ceiling below Attic: Minimum Insulation R-value (IP)	Floor (suspended): Minimum Insulation R-value (IP)
Nunavut – Good Building Practices, 2005	**R-28 (nominal)**	**R-40 (nominal)**	**R-40 (nominal)**
Northwest Territories – Good Building Practices, 2011	**R-32 (nominal)**	**R-50 (nominal)**	**R-40 (nominal)**
Yellowknife – Existing Buildings	**R-30 (nominal)**	**R-40 (nominal)**	**R-30 (nominal)**
Yukon Housing Corporation	**R-28 Whitehorse R-21.9 elsewhere (effective)**	**R-59 (effective)**	**R-28.5 (effective)**
General Passive House Guidelines	**R-60 to R-80+ (effective)**	**R-60 to R-100+ (effective)**	**R-40 to R-80+ (effective)**

Optimal Wall Design Prerequisites

Exterior walls in northern climates are subject to extreme colds, intense winds, snow in various forms and high temperatures with many months of solar exposure. These walls must therefore be able to:

- → Support structural loads, including wind, gravity, snow, and sub-surface movements.
- → Control the following environmental loads:
  - o Moisture, either as precipitation, blowing snow, frost, air leakage condensation, or indoor water vapour;
  - o Air, by providing continuous air barrier systems to minimize losses to the exterior resulting in condensation to the enclosure and increased heating costs; and
  - o Heat, by providing sufficient thermal resistance to minimize heat loss to the exterior during the winter, and minimize heat gains during the summer.
- → Provide a durable finish, resistant to impact loads and occupant use of the building.

In addition to the above, the walls must be affordable, either light in weight or compact in volume to minimize shipping costs, and simple to build and maintain.

This section discusses the major approaches towards achieving high R-value walls. Optimization research by NRCan for the Energy Efficiency Guideline for the Yukon identified approximately R-40 (RSI-7.0) effective walls as being optimal for these conditions. Therefore, the R-40 effective requirement will form the basis for the selection of the candidate wall system. Higher (and lower) R-values can be achieved in all of the analyzed wall assemblies by adjusting the thickness of the assembly and insulation to suit.

The individual evaluation of each wall types based on the performance criteria may be found in the relevant appendices.

Structural and Support Functions

All walls are required to support structural loads from the building, wind and lateral loads from the environment, while providing space for running services such as electrical and communications. The support function of walls is typically achieved with wood stick-framing, sheathed for shear and lateral loads with plywood or oriented strand board, and finished with gypsum wall board for fire protection and aesthetics. The low cost and effectiveness of this structural system is therefore adopted as the basis for the proposed wall types.

Moisture Control

Controlling moisture involves the careful balancing of wetting and drying forces on a wall, ensuring that the amount of moisture in the wall does not exceed its safe storage limit. Exterior moisture sources include rain, snow, and mist, while interior source are predominantly from home use (e.g. cooking, cleaning, etc).

Precipitation is controlled predominantly by the cladding and the water resistive barrier. All proposed systems feature a rain-screened cladding system. This system involves the use of furring strips (e.g. 1x2 or 1x3 dimensional lumber or ½” to ¾” plywood strips cut to 1.5” to 3” widths) to create a ventilated space behind the cladding. The cladding is then fastened with standard fasteners to these furring strips.

Ventilating the cladding ensures longer durability of the cladding material, promotes drying of the cladding and the wall assembly, and protects against water ingress in to the wall assembly by acting as a capillary break. Face-sealed or concealed barriers (e.g. cladding installed directly against the building paper or housewrap) are discouraged, as airflow and capillary break behind the cladding is eliminated, reducing the drying potential.

Moisture control from indoor humidity must be considered in conjunction with the placement of the thermal insulation. Cavity insulated walls require interior vapour control, typically polyethylene sheet, and an interior air barrier that is continuous and sealed at all penetration and transitions. For walls with exterior insulation, the placement of the vapour and air barrier must be assessed individually, depending on the type and thickness of exterior insulation. Each wall assembly will provide recommendations on optimal positioning of the air and vapour barriers.

Air Leakage Control

After controlling precipitation, control of airflow through the building is the second most important function of the building enclosure. The primary concern of air leakage is not heating costs, but failure of structural members caused by air leakage condensation. Enclosure elements that are not maintained above the dew-point temperature of the interior air are at risk air leakage condensation, resulting in decay of organic materials, corrosion in metals, or spalling in ceramics. The secondary and tertiary benefits are decreased heating costs and better control of indoor air quality, respectively. While air leakage is not considered as a separate performance criterion in the assessment, it is grouped under 'moisture durability' in the evaluations.

In all air tight-homes, proper mechanical ventilation systems are required. Heat recovery ventilators are necessary and are fairly common in most areas of the North

Thermal Resistance of Wall Assemblies

The NRCan Energy Efficiency Guideline for the Yukon identified R-40 effective walls as being optimized from a cost performance perspective over the life-span of the building in cold climates. With better insulated walls, the heating requirements for the building are lessened. As space heating forms the predominant energy requirements to operate a building in the North, minimizing the required amount of heating will result in significant savings to the owners.

Heat flow is resisted by insulation, but if conductive elements, like wood studs, pass through the insulation, the overall thermal resistance is reduced. This phenomenon is known as thermal bridging. Thermal bridging reduces the effectiveness of the insulation, requiring more insulation to compensate for the loss in performance. Wall assemblies that effectively use insulation will invariably perform better than those that do not.

As the temperature of the components in a wall assemblies greatly impacts the moisture durability, it is important to recognize that placement and quantity of the insulation plays a significant role in the overall durability of the assembly. Walls where the moisture sensitive materials are kept warm are at a lesser risk of deterioration.

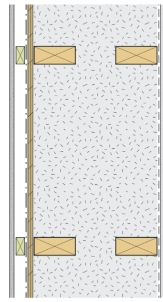
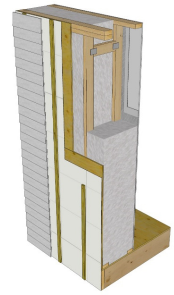
Constructability, Cost, and Resource Efficiency

An ideal wall must be able to perform all of its requisite functions of structure and control, but must also be done in a cost effective manner. Constructability, cost, and resource efficiencies are all closely related, as the end results are all measured in dollars. In remote areas, simplicity in design and construction, cold weather compatibility of materials, trade availability, and reparability are key considerations. Efficient use of material, for both structural and control functions, is also critical, as labour intensive design become cost prohibitive, and inefficient use of materials results in additional shipping costs and construction waste.

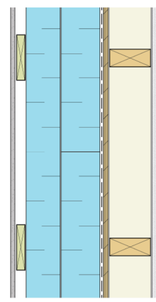
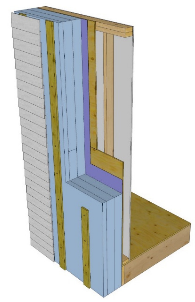
Wall Types and Variations

Four different wall types were identified, with variations to each, for a total of 16 different wall assemblies. The wall types were based the different insulation approaches. The four wall types are:

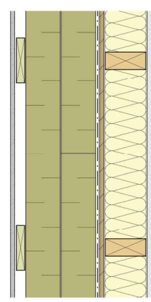
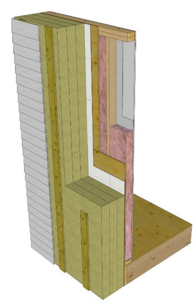
1) Cavity Insulated Walls: Walls where the insulation is placed between the structural framing members or between the structural sheathing and the gypsum wall board. Cavity insulated walls are sometimes referred to in literature as ‘stud insulated’ or ‘interior insulated’ as insulation is placed inboard of the sheathing. Cladding is attached directly to the sheathing following traditional practices.

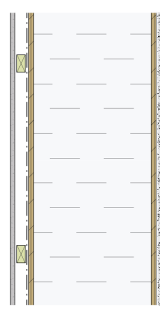
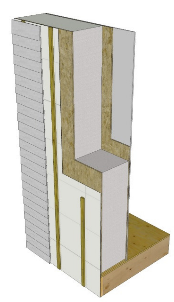
2) Exterior Insulated Walls: Walls where all of the insulation is placed outside of the structural sheathing and framing. Numerous techniques including long fasteners and vertical strapping and various clips are used to attach cladding to this wall assembly.

3) Split Insulated Walls: Walls where exterior insulation is used in conjunction with cavity insulation between the studs. Numerous techniques including long fasteners and vertical strapping and various clips are used to attach cladding to this wall assembly.

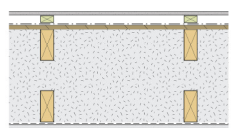
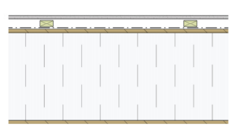
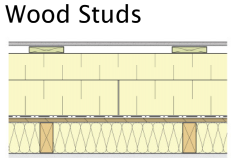



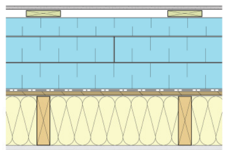
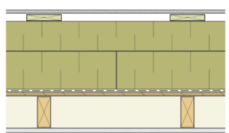
4) Insulated Structures: Commonly encountered as structural insulated panels (SIPs), these systems use the structural capacity of insulation to support building loads. Cladding is attached directly to the structural panel sheathing following traditional practices.

One option that was not considered was the use of insulation inboard of the stud framing. While this approach is sometimes favoured for sheltering workers during construction in adverse weather conditions, the wall is inherently susceptible to durability concerns caused by air leakage condensation. Further, the wall’s design restrict drying, does not adequately address thermal bridging concerns, and is structural inefficient by using up floor space that could otherwise be used by the occupants. This assembly does not readily achieve an effective R-40 as covered within this report, typically maxing out between R-20 to R-30 effective depending on framing choices.

Within each wall type are multiple variations, from sheathing types, sheathing membranes, and insulations. The list of all assessed wall types are found in Table 2. For simplification, typical materials and installation for each of the 16 walls are provided in the appendix in their respective evaluation charts. The charts are broken down into typical construction and materials and their relative performance for northern climates. All of these proposed walls achieve a minimum effective R-value of R-40 at a design temperature of -20˚C as covered in Appendix B. Note that the four walls with 2x6 framing exceed R-65 in order to maintain sufficient exterior to stud cavity insulation ratios to prevent the risk of air leakage condensation within the cavity.

TABLE 2 – CANDIDATE WALL TYPES, CATEGORY, AND INSULATION TYPE AND THICKNESS					
Wall	Wall ID	Wall Description	Insulation Type	Insulation Nominal R-value at -20˚C	Assembly Effective R-value at -20˚C
1a	D-CFI	Double Stud Wall 	13.5” Dense-Packed Cellulose Insulation (CFI)	57.8	41.1
1b	D-FG		14” Fibre-glass Batt Insulation (FG) - (with 2x 3.5” R-13 batts and 1x ~7” R-28 batt)	56.0	42.3
2	D-ocSPF		13” Open-Cell Spray Polyurethane Foam (ocSPF)	58.5	40.0
3	D-ccSPF		5” Closed-Cell Spray Polyurethane Foam and ~7” R-28 Fiberglass batt insulation (FG)	60.7	40.3
4	SIPS	Structural Insulated Panels 	8” Expanded Polystyrene (EPS) Insulation	40.0	40.0
5	S4-EPS	Split Insulated Wall on 2x4 Wood Studs 	6.5” Expanded Polystyrene (EPS) Exterior Insulation and R-13 Fibreglass Batt Insulation	44.9	43.5
6	S4-XPS		5” Extruded Polystyrene (XPS) Exterior Insulation and R-13 Fibreglass Batt Insulation	44.5	43.1
7	S4-MFI		6” Mineral Fiber (MFI) Exterior Insulation and R-13 Fibreglass Batt Insulation	44.2	42.8

8	S4-PIC		7” Polyisocyanurate (PIC) Exterior Insulation and R-13 Fibreglass Batt Insulation	43.8	42.4
9	S6-EPS	Split Insulated Wall on 2x6 Wood Studs 	10” Expanded Polystyrene (EPS) Exterior Insulation and R-21 Fibreglass Batt Insulation	70.0	65.6
10	S6-XPS		8” Extruded Polystyrene (XPS) Exterior Insulation and R-21 Fibreglass Batt Insulation	71.4	67.0
11	S6-MFI		9.5” Mineral Fiber (MFI) Exterior Insulation and R-21 Fibreglass Batt Insulation	70.4	66.0
12	S6-PIC		11.5” PIC Exterior Insulation and R-21 Fibreglass Batt Insulation	71.6	67.2
13	X-EPS	Exterior Insulated Wall on 2x4 Wood Studs 	8” Expanded Polystyrene (EPS) Exterior Insulation	39.2	40.7
14	X-XPS		6.5” Extruded Polystyrene (XPS) Exterior Insulation	41.0	42.5
15	X-MFI		7.5” Mineral Fiber (MFI) Exterior Insulation	39.0	40.5
16	X-PIC		9” Polyisocyanurate (PIC) Exterior Insulation	39.6	41.1

Candidate Wall Evaluation

The candidate wall assemblies were evaluated for the following performance criteria:

- → Hygrothermal Durability
- → Thermal performance
- → Constructability
- → Cost
  - → Material Availability
  - → Complexity
  - → Trade Availability
  - → Reparability
  - → Resource Efficiency

The details for each assessment may be found in the respective appendices. Whenever possible, numerical values (e.g. dollars, or hours of labour) were attributed to the respective assemblies such that a direct comparison could be made. However, some criteria required subjective assessments.

In all cases, the candidate walls were assessed a score from 0 to 10, with a score of 0 the worst and a score of 10 the best. Explanation of the scoring process is included in each respective criterion. The wall assembly with the highest total score is therefore the ideal northern wall.

Hygrothermal Durability

Durable wall assemblies must be able to safely handle all moisture loads. To determine the candidate wall assemblies' moisture performance, hygrothermal simulations were performed. To represent a range of climates across the North, three cities were selected for the modeling: Whitehorse, Yellowknife, and Iqaluit. The wall assemblies were deemed to pass if the structural sheathing did not reach a moisture content greater than 28% MC, or the fibre saturation point, a level that is correlated to mould and decay.

To provide a degree of realism to the simulations, a small air leak, representative of the amount of air flowing through a code compliant wall, was also simulated. If the structural sheathing achieved a moisture content greater than 28% MC under these conditions, the wall assembly was deemed to have failed the hygrothermal durability criterion.

Thermal Performance

The wall assemblies were analyzed to determine their effective thermal performance. Two-dimension steady state models or parallel path method calculations were used to assess the thermal performance of the wall assemblies. The minimum required functional R-value was set to R-40. The assumed R-values for the insulations were determined under realistic temperature conditions, based on modified ASTM tests. Nominal R-value, based on tested material data at 24°C (75°F) FTC values and -20°C (-4°F), and effective R-value, including thermal bridging and temperature-dependent thermal conductivity, were conducted. As all of the wall assemblies were designed to meet a minimum effective R-40 at -20°C, the thermal efficiency can be determined by comparing the nominal R-values of the respective walls. The score for the wall assemblies were derived by dividing the wall's nominal R-value to the least and most thermally insulated wall assemblies, normalized to a score of 1 to 10.

Constructability

Constructability is the ease and efficiency with which an assembly can be built. Consideration for potential sequencing obstacles, delays or cost overruns must also be considered. The constructability of the wall assemblies is rated subjectively, based on experience on building and detailing wall assemblies and interviews with northern builders. In general, the more a wall assembly requires careful attention to detail to ensure proper operation (e.g. air sealing at every penetration, joint, and interface), the less it is constructible. For instance, wall assemblies with significant exterior insulation require unique details to address windows, doors, and other penetrations. Therefore a wall assembly with significant exterior insulation is less constructible than one with less exterior insulation. Similarly, a wall that requires extreme attention to air sealing detailing will be less constructible than a wall with a simpler air barrier system.

As the other metrics are based on a 10 point system, the scoring system for constructability is based on the following:

- → Poor: 3 to 4
- → Moderate: 5 to 6
- → Good: 7 to 8
- → Excellent: 9 to 10

Construction Cost

The cost of the wall assemblies encompasses all performance criteria to which a dollar value can be attributed. Wall assemblies that do not effectively use thermal insulation require more, thereby increasing shipping and crating fees; increased assembly complexity requires additional labour; and more specialized or high performance materials have greater material costs. In this way, resource efficiency, material weight and volume, constructability and complexity, as well as the cost of the actual materials used in the assembly were combined as an aggregate rating for cost. The score for the wall assemblies were derived by dividing the wall's cost proportionally to the least and most expensive wall assemblies, normalized to a score of 1 to 10.

Performance Summary

The evaluation of each wall assembly can be found in Table 3. The walls were rated on a scale of 1 to 10, with 10 being a better performing wall under the respective metric.

TABLE 3– CANDIDATE WALL TYPES EVALUATION (R-40 AND *R-60+* OPTIONS)							
Wall	Wall ID	Hygrothermal Assessment	Effective R-value at -20˚C	Thermal Efficiency	Constructability	Cost	Score
1a	D-CFI	Fail	41	7	Moderate (5)	6	18
1b	D-FG	Fail	42	7	Moderate (6)	10	23
2	D-ocSPF	Pass	40	7	Poor (4)	4	15
3	D-ccSPF	Pass	40	6	Poor (3)	5	14
4	SIPS	Pass	40	10	Moderate (5)	5	20
5	S4-EPS	Pass	43	9	Excellent (9)	8	26
6	S4-XPS	Pass	43	9	Excellent (10)	7	26
7	S4-MFI	Pass	43	9	Excellent (9)	6	24
8	S4-PIC	Pass	42	6	Good (7)	6	19
9	*S6-EPS*	*Pass*	*66*	*5*	*Good (8)*	*6*	*19*
10	*S6-XPS*	*Pass*	*67*	*5*	*Good (8)*	*4*	*17*
11	*S6-MFI*	*Pass*	*66*	*6*	*Good (8)*	*2*	*16*
12	*S6-PIC*	*Pass*	*67*	*1*	*Good (8)*	*2*	*10*
13	X-EPS	Pass	41	10	Good (7)	7	24
14	X-XPS	Pass	42	10	Good (7)	6	23
15	X-MFI	Pass	41	10	Good (7)	5	22
16	X-PIC	Pass	41	6	Good (7)	4	17

The results of the evaluation indicate that 2x4 wood frame wall with 5" of XPS and 6.5" of EPS provide the best balance of thermal efficiency, constructability, and cost. Alternately the use of 6" of MFI is comparable in terms of performance, however, when shipping costs to remote communities is considered it is more expensive due to the increased weight of this type of rigid insulation. Within Whitehorse and Yellowknife costs for the 2x4 wall with exterior EPS, XPS and MFI insulations are very similar for the same target effective R-value.

Details on the assessment of the wall assemblies may be found in their respective appendices.

Optimal Wall for Northern Climates

By assessing the performance of each of the candidate walls on a multitude of performance criteria, the wall assembly that ranked highest on the relative assessment was selected as the ideal wall. As premature failure of the wall assembly is unacceptable, only walls that passed the hygrothermal simulation test were considered. Thereafter, the walls were evaluated based on cost, constructability, and thermal performance. Even considering additional costs for shipping, crating, and increased labour for the remote areas of the North, the optimal wall for major population centres was also the optimal wall for remote communities.

Analysis of the results indicate that a 2x4 framed split insulated wall assembly with 5" of extruded polystyrene insulation (XPS) or 6.5" of expanded polystyrene (EPS) and R-13 batt meets the required hygrothermal performance, is readily buildable without any specialized trades or skillsets, and optimizes material costs with labour costs. At near equal cost and durability is the same assembly except 6" of semi-rigid mineral fibre (MFI) insulation. Figure 3 shows an isometric cut-away of the ideal northern wall, and Table 4 shows the construction sequencing.

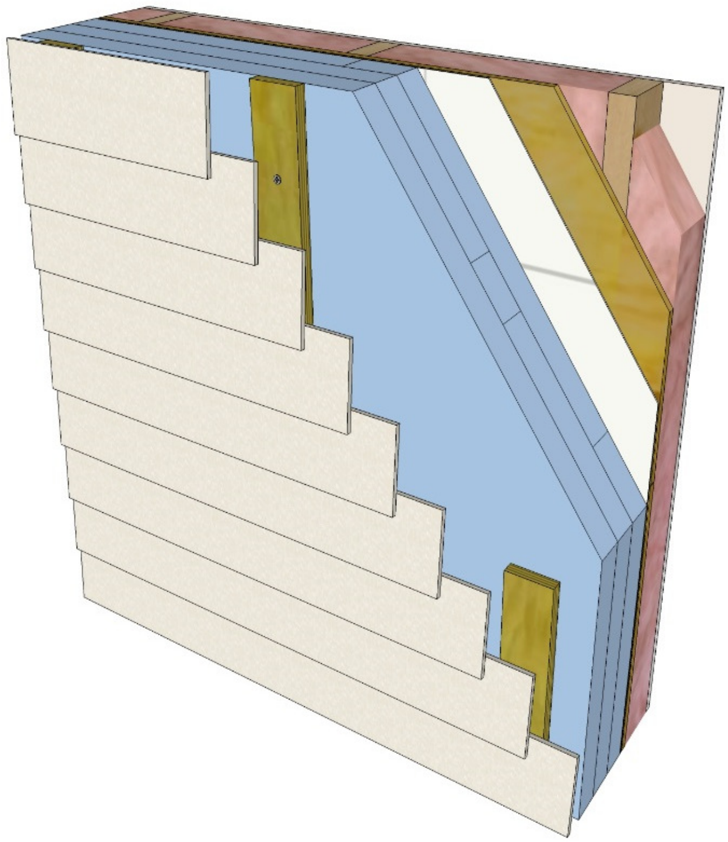
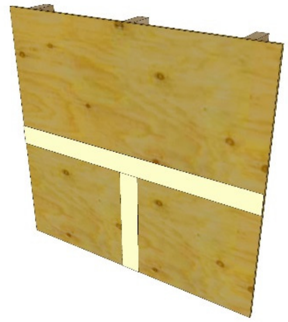
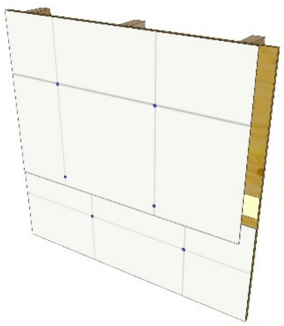
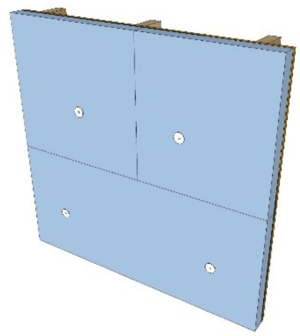
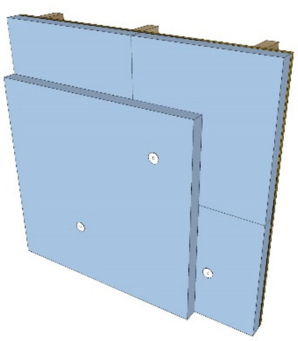
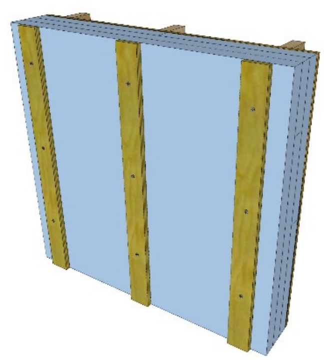
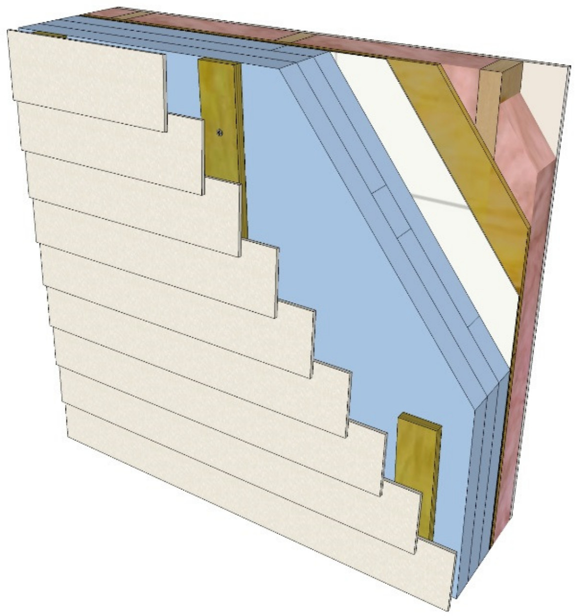


Figure 3 – Isometric Cutaway of the Ideal Northern Wall: 5" of XPS shown in more than one layer, Fastened with 7" Screws over a 2x4 wood framed wall, Taped Sheathing as the Air Barrier, and R-13 Cavity Batt Insulation.

Note that no additional interior vapour or air barrier (6 mil poly) is required and when XPS or EPS is used on the exterior should not be added at the interior. If MFI were used on the exterior then poly on the interior would be acceptable to use (though not needed).

TABLE 4 STEP-BY-STEP INSTALLATION SEQUENCE FOR THE IDEAL NORTHERN WALL

	
Frame wall with 2x4 wood studs on 16" centres. Sheath with plywood or OSB.	Install minimum 3" wide tapes or self-adhered membrane (e.g. NovaFlash SA or similar cold weather sticky tape/membrane) along all sheathing edges to form air barrier system with structural sheathing.
	
Install building wrap sheathing membrane with cap-nails. Ensure all laps are positive and seams are offset. *Alternately the building wrap can be taped here as the primary air barrier element.*	Install first layer of XPS insulation, ensuring joints are staggered. Tack in to place as required.
	
Install subsequent layers of insulation with joints staggered and offset. Tack in to place as required. Combine insulation layers in more than one, and ideally no more than 3 layers.	Install 1x3 furring strips, of either dimensional lumber or plywood cut to size, and fasten through with long screws.



Finish the wall assembly with the cladding of choices

TIPS AND TRICKS	
1	Building a temporary shelf along the bottom of the wall can help with stacking insulation quickly. Fill out the bottom most row of insulation and install the furring strip vertically with two screws. Use the furring strips as forms and continue to stack the insulation, ensuring joints are staggered and offset. Then install remaining screws to fasten furring strip.
2	Windows are best installed in plywood window bucks that extend out through the insulation. Flanged windows can be installed on built-out frames around the window opening. Ensure any built-out structures are fully waterproofed and air sealed.
3	The same insulation approach can be used on sloped roofs and under floor slabs: install the sheathing membrane, tack the insulation in to place, install the furring strips, and then finish with desired cladding, roofing material, or panelized system.

Appendix A - Performance: Durability

Appendix A – Hygrothermal Simulations

Durable wall assemblies must be able to safely handle all moisture loads. To determine the candidate wall assemblies' moisture performance, hygrothermal simulations were performed. To represent a range of climates across the North, three cities were selected for the modeling: Whitehorse, Yellowknife, and Iqaluit. The wall assemblies were deemed to pass if the structural sheathing did not reach a moisture content greater than 28% MC, or the fibre saturation point, a level that is correlated to mould and decay.

Hygrothermal Modeling

Hygrothermal modeling was undertaken using WUFI Pro 5.3. The identified walls were created in the program using the most representative materials available.

The exterior boundary conditions were created using available airport weather data for Whitehorse, Yellowknife, and Iqaluit. The interior boundary conditions were based on EN 15026 and verified with data by Rousseau et al, (2007)[1]. To assess more realistic conditions, the simulations also included the impacts of a small air leak ($0.2\ L\cdot m^{-2}\cdot s^{-1}$), representative of the maximum air leakage value from CAN/ULC-S742, de-rated to natural wind pressures (4 Pa). Figure A-1Figure A shows a print-out of a sample wall assembly in WUFI Pro.

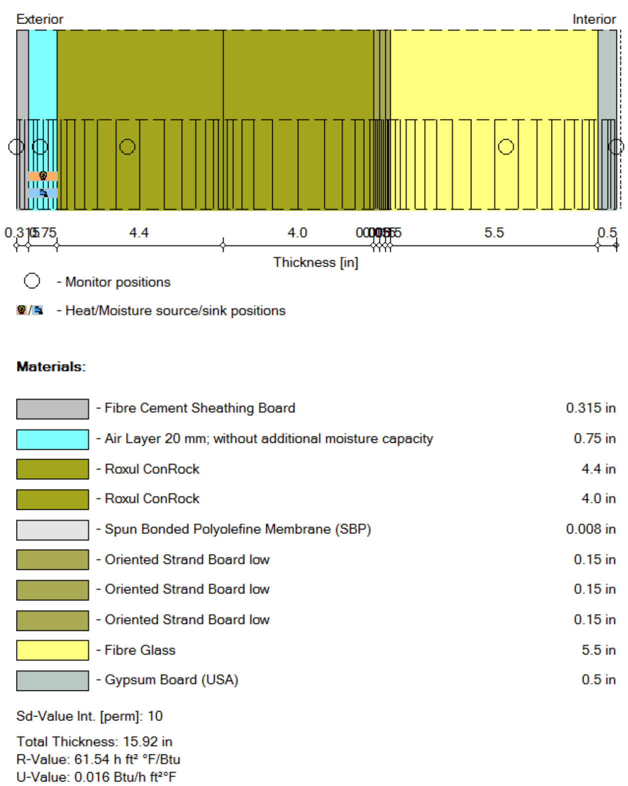


Figure A-1 – WUFI Simulation Screen Capture for Split Insulated Assembly with 6.5" of Exterior Mineral Fibre Insulation and R-19 Fibreglass Batt Insulation

[1] Rousseau, M., Manning, M., Said, M., Cornick, S., Swinton, M. 2007. Characterization of Indoor Hygrothermal Conditions in Houses in Different Northern Climates. Atlanta: ASHRAE.

Results

All the wall assemblies performed well under ideal conditions; the moisture content of the sheathing did not exceed 20% in any case and in all locations. The combination of rain-screen cavity and perfectly sealed interior vapour and air barrier in the cavity insulated walls resulted in moisture contents not exceed 15%. The Control (2x6 with R-21 batt), Double-stud wall with dense-pack cellulose insulation (D-CFI), Exterior insulated assembly with XPS insulation (X XPS) and the split insulated wall assembly with XPS exterior insulation (S XPS) are shown in Figure A-4. The performance of all of the split insulated assemblies were nearly identical; the same was true of the exterior insulated assemblies. For simplicity, only a single assembly is shown in the analysis.

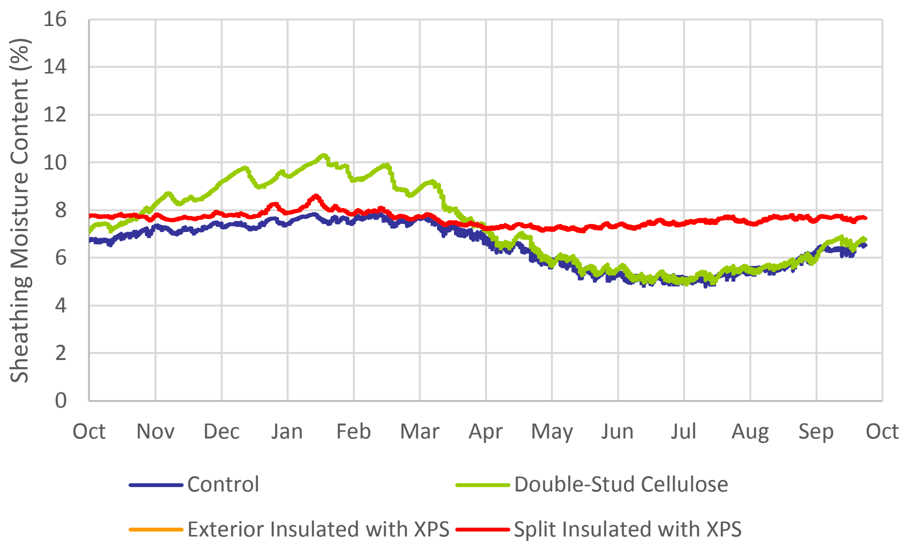


Figure A-2 – Moisture Performance of Control, D-CFI, X-XPS, and S-XPS Wall Assemblies, in Whitehorse, YT

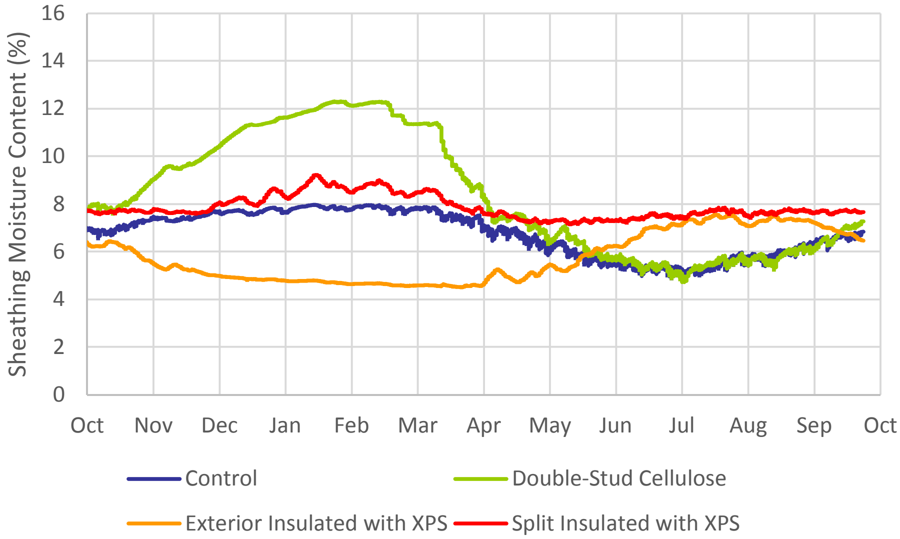


Figure A-3 – Moisture Performance of Control, D-CFI, X-XPS, and S-XPS Wall Assemblies, in Yellowknife, NT

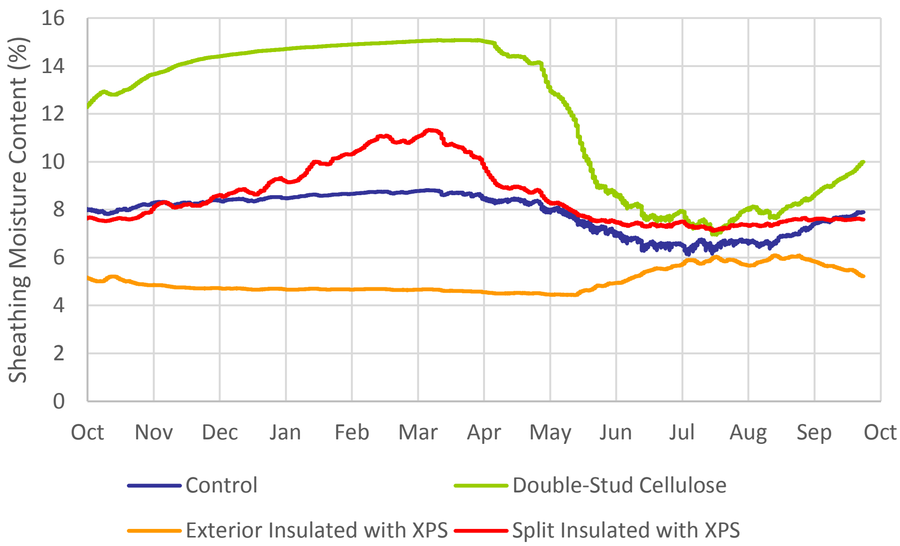


Figure A-4 – Moisture Performance of Control, D-CFI, X-XPS, and S-XPS Wall Assemblies, in Resolute Bay/Iqaluit, NU

However, the performance of cavity insulated walls perform much worse once a nominal air leak is introduced. The difference in performance between the idealized double stud wall and the split insulated wall, with and without air leaks, is shown in Figure A-7.

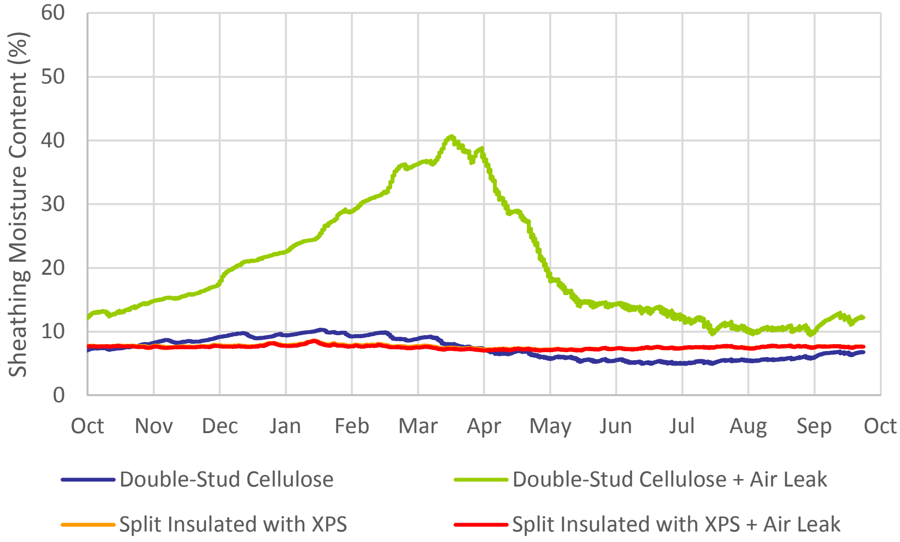


Figure A-5 – Difference in Moisture Performance under Idealized and Realistic Conditions, for Double Stud and Split Insulated Wall Assemblies, in Whitehorse, YT

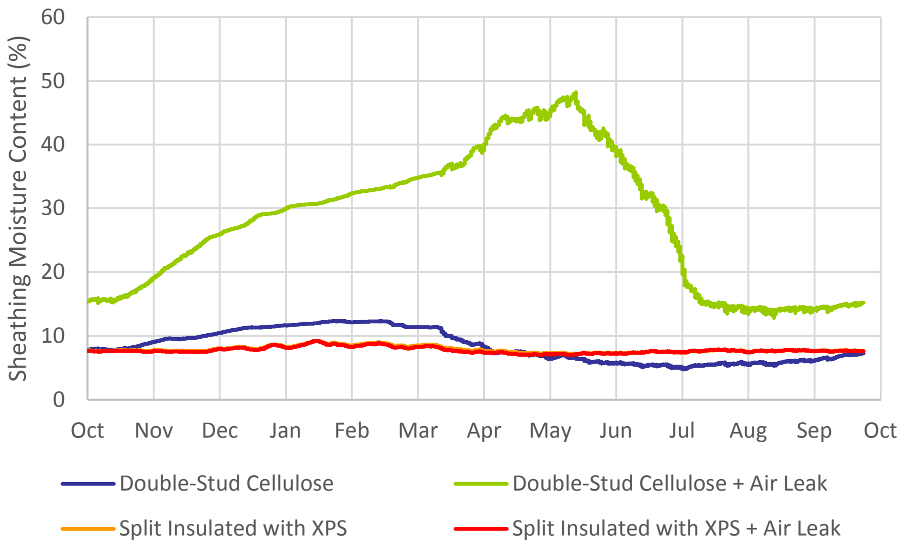


Figure A-6 – Difference in Moisture Performance under Idealized and Realistic Conditions, for Double Stud and Split Insulated Wall Assemblies, in Yellowknife, NT

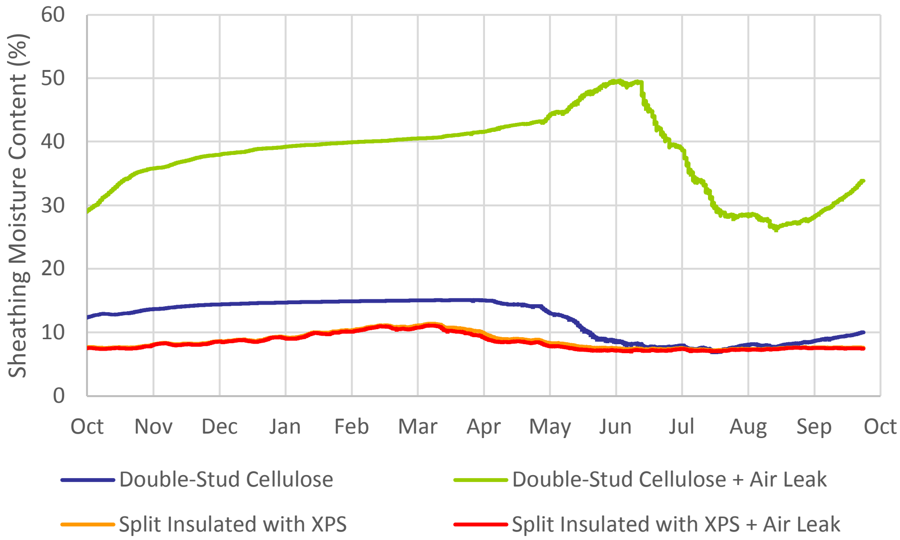


Figure A-7 – Difference in Moisture Performance under Idealized and Realistic Conditions, for Double Stud and Split Insulated Wall Assemblies, in Resolute Bay/Iqaluit, NU

Moisture contents in excess of 28% are considered to be at extreme risk of decay. The double-stud wall assembly with cellulose insulation performs significantly worse with nominal air leakage. The only other wall to fail the air leakage test was the 2x6 Control wall. All the other wall assemblies provided a degree of resistance from air leakage decay and are therefore considered to pass the hygrothermal assessment criteria. The results are summarized in Table A-1.

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TABLE A-1 – HYGROTHERMAL DURABILITY SUMMARY			
Wall	Wall ID	Hygrothermal Assessment	Notes
C	Control	Fail	Failed by air leakage
1a	D-CFI	Fail	Failed by air leakage
1b	D-FB	Fail	Failed by air leakage
2	D-ocSPF	Pass	Spray foam insulation functions as the air barrier and protects the sheathing from air leakage. Therefore no cracks, gaps or defects may be present within the foam after curing and in-service.
3	D-ccSPF	Pass	Spray foam insulation functions as the air barrier and protects the sheathing from air leakage. Therefore no cracks, gaps or defects may be present within the foam after curing and in-service.
4	SIPS	Pass	Locations for air leakage decay are at the joints between panels. Therefore joint detailing and sealing is absolutely critical to the long term performance of this assembly.
5	S4-EPS	Pass	Sheathing is above the dewpoint.
6	S4-XPS	Pass	Sheathing is above the dewpoint.
7	S4-MFI	Pass	Sheathing is above the dewpoint.
8	S4-PIC	Pass	Sheathing is above the dewpoint.
9	S6-EPS	Pass	Sheathing is above the dewpoint.
10	S6-XPS	Pass	Sheathing is above the dewpoint.
11	S6-MFI	Pass	Sheathing is above the dewpoint.
12	S6-PIC	Pass	Sheathing is above the dewpoint.
13	X-EPS	Pass	Sheathing is above the dewpoint.
14	X-XPS	Pass	Sheathing is above the dewpoint.
15	X-MFI	Pass	Sheathing is above the dewpoint.
16	X-PIC	Pass	Sheathing is above the dewpoint.

Appendix B - Performance: Thermal

Appendix B – Thermal Performance

The wall assemblies were analyzed to determine their effective thermal performance. Two-dimension steady state models or parallel path method calculations were used to assess the thermal performance of the wall assemblies. The minimum required functional R-value was set to R-40. The assumed R-values for the insulations were determined under realistic temperature conditions, based on modified ASTM tests. Nominal R-value, based on product data at 24˚C (75˚F) FTC values, and effective R-value, including thermal bridging and temperature-dependent thermal conductivity, were conducted. Figure B-1 shows the temperature dependant plots for common insulations, whereas Table B–1 shows the assumed nominal and effective R-values for the calculation of the thermal resistance of the candidate wall assemblies.

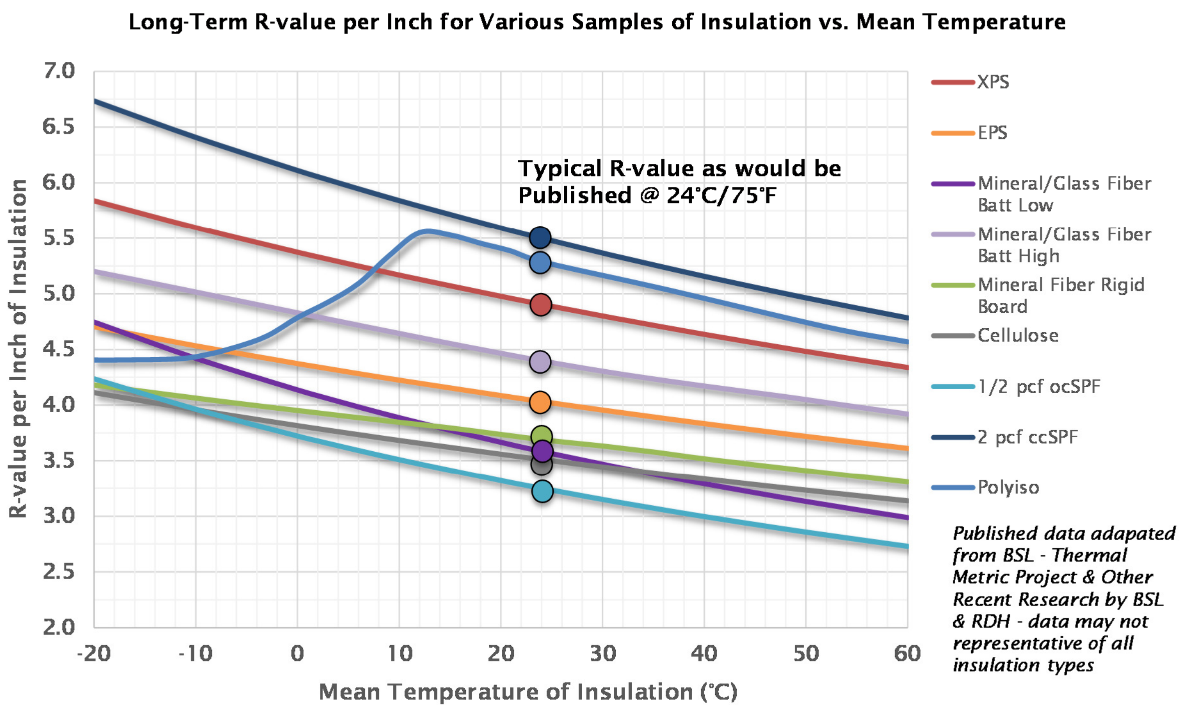


Figure B-1 – Temperature Dependant R-values for Common Insulation Materials

TABLE B-1 – ASSUMED NOMINAL AND TEMPERATURE-DEPENDANT THERMAL CONDUCTIVITY FOR SELECT INSULATION MATERIALS		
Insulation Type	**Nominal Conductivity (24°C) W/m·K (R-value/inch)**	**Cold Temperature Conductivity (-20°C) W/m·K (R-value/inch)**
Extruded polystyrene	0.029 (R-5)	0.023 (R-6.3)
Expanded polystyrene	0.036 (R-4)	0.029 (R-4.9)
0.5pcf open-cell Spray Polyurethane Foam	0.040 (R-3.6)	0.032 (R-4.5)
2pcf closed-cell Spray Polyurethane Foam	0.024 (R-6)	0.02 (R-7.1)
Polyisocyanurate	0.024 (R-6)	0.033 (R-4.4)
Semi-Rigid Mineral Fibre	0.036 (R-4)	0.028 (R-5.2)
Dense-pack Cellulose Fibre Insulation	0.040 (R-3.6)	0.034 (R-4.28)
Fibreglass Batt Insulation	0.039 (R-3.7)	0.036 (R-4)

For the split insulated assemblies, and the closed-cell SPF double-stud wall, the required amount of exterior insulation to mitigate air leakage condensation was determined. Using the insulation ratio, which is the ratio of exterior insulation to the entire assembly's R-value, in such a way that the condensing plane does not fall below the interior dew point temperature results in conservative estimates. However, even under adverse conditions, these will assemblies are at extremely low risk of pre-mature failure. The insulation ratios used are shown in Table B–2. The assumed conditions for the insulation ratios are a -40°C outdoor temperature and 30% interior relative humidity. Research by the National Research Council indicates that high humidity loads (i.e. 30% RH) is not uncommon in northern buildings. When further combined with an extremely airtight enclosure, higher relative humidity levels are anticipated. A value of 30%RH is assumed to be a balanced blend of managing increased air tightness with periodic moisture generating activities. Even if the RH were to be assumed at a lower threshold of 20% RH at -40°C, the insulation ratio only changes by a small margin (70% to 66%).

TABLE B–2 – INSULATION RATIO OF EXTERIOR TO INTERIOR INSULATION TO CONTROL AIR LEAKAGE CONDENSATION					
Indoor RH / $T_{outdoor}$ (°C)	20%	30%	40%	50%	60%
0	0	0.12	0.32	0.47	0.6
-10	0.23	0.4	0.54	0.64	0.73
-20	0.41	0.55	0.65	0.73	0.8
-30	0.53	0.64	0.72	0.78	0.84
-40	0.66	0.70	0.76	0.82	0.86

Consequently, the insulation requirements were determined and calculated to achieve either a minimum effective R-40 and surpass the insulation ratio requirement, as required (e.g. up to approximately R-70). Achieving the insulation ratio is a requirement to ensure hygrothermal durability. While there is a degree of storage capacity in the sheathing which may allow for slightly lower insulation ratios, deviating from the recommended insulation ratio removes the factor of safety from high occupant moisture generation, such as showering or cooking. These spikes, if sufficiently frequent, may result in mould growth in the affected areas. The results for the effective clear-wall R-values are shown in Table B-3. Nominal insulation R-value is the thermal resistance of the wall assemblies excluding any thermal bridging elements, like wood studs. The R-values for the nominal insulation are those reported at the standard 24°C (75°F) FTC value. The effective assembly R-values include the impacts of thermal bridging and temperature dependent insulation conductivity.

TABLE B-3 – WALL ASSEMBLY NOMINAL AND EFFECTIVE R-VALUES					
Wall Assembly	**Insulation Type**	**Insulation Thickness (inch)**	**Nominal Insulation R-value at 24°C**	**Effective Assembly R-value at 24°C**	**Effective Assembly R-value at -20°C**
Double-stud wall	Cellulose	13.5	48.7	38.4	41.1
Double-stud wall	Fiberglass	14	51.8	41.0	42.3
Double-stud wall	ocSPF	13	46.9	36.6	40.0
Double-stud wall	ccSPF/Batt	5/7	55.3	38.2	40.3
SIPS	EPS	8	32.0	32.0	40.0
Split-Insulated on 2x4 Framing	EPS/Batt	6.5/3.5	39.0	37.6	43.5
Split-Insulated on 2x4 Framing	XPS/Batt	5/3.5	37.9	36.5	43.1
Split-Insulated on 2x4 Framing	MFI/Batt	6/3.5	37.0	35.6	42.8
Split-Insulated on 2x4 Framing	PIC/Batt	7/3.5	55.1	53.7	42.4
Split-Insulated on 2x6 Framing	*EPS/Batt*	*10/5.5*	61.1	56.7	65.6
Split-Insulated on 2x6 Framing	*XPS/Batt*	*8/5.5*	60.8	56.4	67.0
Split-Insulated on 2x6 Framing	*MFI/Batt*	*9.5/5.5*	59.1	54.7	66.0
Split-Insulated on 2x6 Framing	*PIC/Batt*	*11.5/5.5*	90.1	85.7	67.2
Exterior Insulated	EPS	8	32.0	33.6	40.7
Exterior Insulated	XPS	6.5	32.3	33.9	42.5
Exterior Insulated	MFI	7.5	30.0	31.6	40.5
Exterior Insulated	PIC	9	54.1	55.6	41.1

In general, the R-value of the wall assemblies increases slightly, as many of the insulation types have superior thermal resistance at lower temperatures, the main exception being polyisocyanurate insulation. The difference between the nominal insulation and effective assembly also includes the impact of wood studs. When applicable, a framing factor of 23% was used to determine the effective R-values of each of the assemblies. The double-stud wall with close-cell spray foam experienced a significant decrease in performance, despite high performance insulation. This decrease in R-value is a result of the sprayfoam insulation being thermally bridged by the much more conductive wood studs.

Appendix C - Performance: Cost and Constructability

Appendix C – Cost, Constructability, and Resource Efficiency

Due to the limited resources available in Northern Canada and the costs of shipping materials, it is important to minimize weight and volume of the construction materials to reduce material costs and shipping costs. This appendix covers how the shipping volume and weight were calculated for each of the 17 different wall types.

For the purpose of this report, 17 different wall assemblies with various framing, insulation, and insulation thickness (as listed in Table C-1) were examined. In order to determine the volume and weight of material used in each assembly, six different 4' by 8' wall frame sections were modelled in Athena Impact Estimator for Buildings Software. Athena allows the user to input in the basic framing layout and materials, as seen in Figure C-1 as well as any additional layers such as gypsum and membranes. This model was then used to generate a bill of materials for each wall frame which included the quantity and weight for each required material. The program also adds a little extra material in order to account for waste during the construction of the wall.

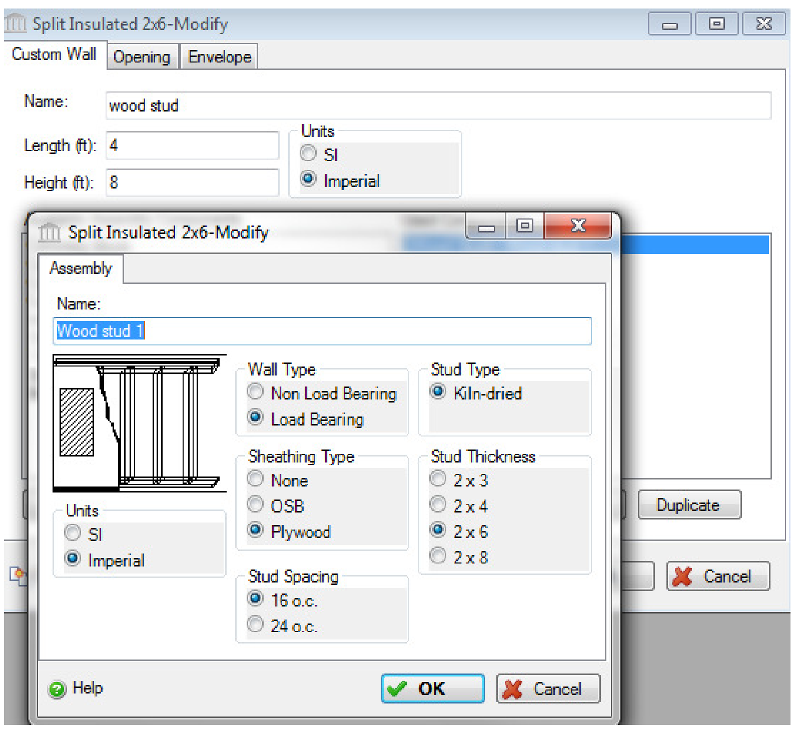


Figure C-1- Inputs Required to Create a Wood Stud Wall Frame in Athena

Using the material quantity and mass calculated by the Athena software the weight and volume per square foot could be calculated for the wall framing. Material with a small volume such as nails or joint compound were considered negligible. Once the material volumes were calculated they were added. For all the wall frames, shipping weight did not vary appreciably from assembly weight but shipping volume did vary from assembly volume when split-insulation was used, due to the incompressibility of many of the rigid insulation.

The weight and volume of the insulation was calculated independently of the wall frames in order to accommodate the different thickness of material required to reach different R-values. The density of all the insulations can be seen in Table C-3. Also listed for each insulations is a shipping weight and volume compression factor which is used to account for the difference in the packaging of the material compared to when it is installed. Shipping weight for the insulation was calculated by multiplying the insulation density by the thickness (in feet) and multiply by the shipping weight compression factor, as required. Shipping volume was calculated by multiplying thickness (in feet) by the volume compression factor. The insulation volume and weight per square foot was then added to the wall frame shipping weight and volume per square foot to get the total wall assembly shipping weight and volume per square foot.

Using the above method the total wall assembly shipping weight and volume per square foot for the 16 different wall assemblies was calculated and can be seen in Table C–2. When shipping building materials to remote communities the cost is calculated either per kg or per cubic meter. The cost quoted at the time of this report was \$390 CAD, for either 1000 kg or 2.5 m^3 of shipped material, whichever is greater. The calculated shipping cost for each wall assembly can be seen in Table C–1.

TABLE C-1– WEIGHT AND VOLUME OF NORTHERN WALL R-40 AND R-65+ ASSEMBLIES								
Wall Type	Framing	Primary Insulation	Primary Insulation Thickness (in)	Secondary Insulation	Secondary Insulation Thickness	Shipping Weight (lbs/sf)	Shipping Volume (cf/sf)	Shipping Cost ($/sf)
Double-stud wall	2x4 S-P-F	Cellulose	13.5	-	-	9.9	0.7	$3.18
Double-stud wall	2x4 S-P-F	Fibreglass	14	-	-	6.8	0.5	$2.29
Double-stud wall	2x4 S-P-F	ocSPF	13	-	-	6.8	0.2	$1.21
Double-stud wall	2x4 S-P-F	ccSPF	5	R-28 FG Batt	7	7.6	0.5	$2.20
SIPS	SIPS	EPS	8			4.1	0.9	$3.82
Split-Insulated	2x4 S-P-F	EPS	6.5	R-13 FG Batt	3.5	5.9	0.8	$3.42
Split-Insulated	2x4 S-P-F	XPS	5	R-13 FG Batt	3.5	6.2	0.6	$2.87
Split-Insulated	2x4 S-P-F	MFI	6	R-13 FG Batt	3.5	8.9	0.7	$3.24
Split-Insulated	2x4 S-P-F	PIC	7	R-13 FG Batt	3.5	6.0	0.8	$3.61
Split-Insulated	*2x6 S-P-F*	*EPS*	*10*	*R-21 FG Batt*	*5.5*	*7.2*	*1.1*	*$5.07*
Split-Insulated	*2x6 S-P-F*	*XPS*	*8*	*R-21 FG Batt*	*5.5*	*7.7*	*1.0*	*$4.34*
Split-Insulated	*2x6 S-P-F*	*MFI*	*9.5*	*R-21 FG Batt*	*5.5*	*12.1*	*1.1*	*$4.89*
Split-Insulated	*2x6 S-P-F*	*PIC*	*11.5*	*R-21 FG Batt*	*5.5*	*7.5*	*1.3*	*$5.63*
Exterior Insulated	2x4 S-P-F	EPS	8	-	-	5.9	0.8	$3.64
Exterior Insulated	2x4 S-P-F	XPS	6.5	-	-	6.3	0.7	$3.09
Exterior Insulated	2x4 S-P-F	MFI	7.5	-	-	9.7	0.8	$3.46
Exterior Insulated	2x4 S-P-F	PIC	9	-	-	6.1	0.9	$4.01

TABLE C-2 – WEIGHT AND VOLUME OF WALL FRAMING							
Wall Type	Materials	Unit	Quantity	Weight (lbs)	Shipping Weight (lbs/sf)	Volume (cf)	Shipping volume (cf/sf)
Double Stud	1/2" Regular Gypsum Board	sf	35.2	58.2	5.98	1.5	0.23
	6 mil Polyethylene	sf	34.0	1.0		0	
	Joint Compound	Tons (short)	0.0	7.2		negligible	
	Nails	Tons (short)	0.0	1.8		negligible	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Small Dimension Softwood Lumber, kiln-dried	cf	4.4	80.0		4.4	
	Softwood Plywood	sf (3/8")	44.7	43.2		1.4	
Split-Insulated 2x4 Wood	1/2" Regular Gypsum Board	sf	35.2	58.2	4.92	1.5	0.23
	FG Batt R11-15	sf (1")	115.5	7.4		9.6	
	Joint Compound	Tons (short)	0.0	7.2		negligible	
	Nails & Screws	Tons (short)	0.0	1.4		negligible	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Small Dimension Softwood Lumber, kiln-dried	cf	2.2	40.0		2.2	
	Softwood Plywood	sf (3/8")	44.7	43.2		1.4	
Split-Insulated 2x6 Wood	1/2" Regular Gypsum Board	sf	35.2	58.2	5.72	1.5	0.32
	FG Batt R20	sf (1")	181.6	10.0		15.1	
	Joint Compound	Tons (short)	0.0	7.2		negligible	
	Nails & Screws	Tons (short)	0.0	1.4		negligible	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Small Dimension Softwood Lumber, kiln-dried	cf	3.5	63.0		3.5	
	Softwood Plywood	sf (3/8")	44.7	43.2		0	

Exterior-Insulated 2x4 Wood	1/2" Regular Gypsum Board	sf	35.2	58.2	4.68	0	0.16
	Joint Compound	Tons (short)	0.0	7.2		1.4	
	Nails & Screws	Tons (short)	0.0	1.0		1.5	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Small Dimension Softwood Lumber, kiln-dried	cf	2.2	40.0		negligible	
	Softwood Plywood	sf (3/8")	44.7	43.2		negligible	
Exterior-Insulated 2x4 steel	1/2" Regular Gypsum Board	sf	35.2	58.2	2.95	2.2	0.16
	Galvanized Studs	Tons (short)	0.0	27.2		1.4	
	Joint Compound	Tons (short)	0.0	7.2		1.5	
	Nails & Screws	Tons (short)	0.0	0.4		2.2	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Screws Nuts & Bolts	Tons (short)	0.0	1.4		negligible	
	Softwood Plywood	sf (3/8")	44.7	43.2		negligible	
SIP (Base Materials with no expanded polystyrene)	1/2" Regular Gypsum Board	sf	35.2	58.2	2.95	negligible	0.2
	6 mil Polyethylene	sf	34.0	1.0		1.4	
	Joint Compound	Tons (short)	0.0	7.2		1.5	
	MDI resin	lbs	3.8	3.8		0	
	Nails	Tons (short)	0.0	1.0		negligible	
	Oriented Strand Board	sf (3/8")	76.6	94.8		negligible	
	Paper Tape	Tons (short)	0.0	0.0		negligible	
	Small Dimension Softwood Lumber, kiln-dried	cf	2.5	45.4		2.4	

TABLE C-3 – WEIGHT AND VOLUME OF INSULATION			
Materials	Density (lbs/cf)	Shipping weight compression factor	Shipping volume compression factor
Blown Cellulose Fibre	1.6	1.00	0.20
Fibreglass Insulation	0.7	1.00	0.25
Open Cell Spray foam	0.5	1.55	0.01
Closed Cell Spray foam	2.0	1.47	0.04
Dense Packed Cellulose Fibre	3.5	1.00	0.44
Extruded Polystyrene	3.0	1.00	1.00
Expanded Polystyrene	1.8	1.00	1.00
Mineral Fibre Insulation	8.0	1.00	1.00
Polyisocyanurate Insulation	1.8	1.00	1.00

Due to the variations in material costs, the labour component of each wall assembly was instead calculated as the number of labour units for construction. This now allows for a regional labour cost to be assigned for each respective zone, either larger population centres or remote communities, respectively. The labour units were calculated using RS Means online data. The labour costs were determined using NRCan data. The labour costs to install exterior insulation assumed that insulation came in thicknesses of 1” and 2” thicknesses. All manufacturers provide rigid insulation boards in thicknesses greater than this amount, but the availability of these thicknesses in northern regions could not be confirmed. Installation of two layers of 3” thick insulation will be less expensive than installation of three layers of 2” thick insulation. The labour units and labour costs for the candidate walls are found in Table C-4.

The total wall costs were calculated including both material and labour costs. The values for Whitehorse, YT, and Yellowknife, NT, only include material and labour costs. The shipping and crating fees determined as part of this work were based on delivery to remote communities and were not strictly applicable to these urban centres and were therefore not included. The costs for Resolute Bay, NU include both material and labour costs as well as shipping costs. Specialized construction equipment (i.e. spray foam and cellulose installation) also include shipping estimates to return the equipment to the supplier. The cost for cladding was not included in these estimates. The typical cladding options in the North (metal, wood etc) do not appreciably impact the performance or determination of cost for the wall assemblies. The total cost, for each respective city, can be found in Table C-5 and cost per effective R-value in Table C-6. Figure C-2 to Figure C-4 plot the presented data for visual reference.

TABLE C-4 – LABOUR UNITS AND LABOUR COST OF NORTHERN WALL R-40 AND R-65+ ASSEMBLIES							
Wall Type	Wood Framing	Primary Insulation	Primary Insulation Thickness (in)	Secondary Insulation	Secondary Insulation Thickness (in)	Labour Units (hours/4x8 Wall)	Labour Costs at $80/hour ($/sf)
Double-stud wall	2x4 S-P-F	Cellulose	13.5	-	-	4.0	$10.10
Double-stud wall	2x4 S-P-F	Fibreglass	14			3.9	$9.70
Double-stud wall	2x4 S-P-F	ocSPF	13	-	-	3.3	$8.30
Double-stud wall	2x4 S-P-F	ccSPF	5	R-28 FG Batt	7	3.8	$9.50
SIPS	SIPS	EPS	8			1.8	$4.40
Split-Insulated	2x4 S-P-F	EPS	6.5	R-13 FG Batt	3.5	3.4	$8.50
Split-Insulated	2x4 S-P-F	XPS	5	R-13 FG Batt	3.5	3.0	$7.50
Split-Insulated	2x4 S-P-F	MFI	6	R-13 FG Batt	3.5	3.0	$7.50
Split-Insulated	2x4 S-P-F	PIC	7	R-13 FG Batt	3.5	3.4	$8.50
Split-Insulated	*2x6 S-P-F*	*EPS*	*10*	*R-21 FG Batt*	*5.5*	*3.9*	*$9.80*
Split-Insulated	*2x6 S-P-F*	*XPS*	*8*	*R-21 FG Batt*	*5.5*	*3.5*	*$8.80*
Split-Insulated	*2x6 S-P-F*	*MFI*	*9.5*	*R-21 FG Batt*	*5.5*	*3.9*	*$9.80*
Split-Insulated	*2x6 S-P-F*	*PIC*	*11.5*	*R-21 FG Batt*	*5.5*	*4.3*	*$10.80*
Exterior Insulated	2x4 S-P-F	EPS	8	-	-	3.0	$7.60
Exterior Insulated	2x4 S-P-F	XPS	6.5	-	-	3.0	$7.60
Exterior Insulated	2x4 S-P-F	MFI	7.5	-	-	3.0	$7.60
Exterior Insulated	2x4 S-P-F	PIC	9	-	-	3.4	$8.60

TABLE C-5 – TOTAL WALL COSTS FOR WHITEHORSE,YT, YELLOWKNIFE, NT, AND RESOLUTE BAY, NU, OF NORTHERN R-40 AND R-65+ WALL ASSEMBLIES

Wall Type	Framing	Primary Insulation	Primary Insulation Thickness	White Horse Cost ($/sf)	Yellowknife Cost ($/sf)	Resolute Cost ($/sf)
Double-stud wall	2x4 S-P-F	Cellulose	13.5	$15.10	$14.70	$27.30
Double-stud wall	2x4 S-P-F	Fiberglass	14	$8.70	$8.90	$14.10
Double-stud wall	2x4 S-P-F	ocSPF	13	$18.60	$19.30	$33.40
Double-stud wall	2x4 S-P-F	ccSPF	5	$20.20	$18.80	$29.30
SIPS	SIPS	EPS	8	$18.10	$18.20	$28.90
Split-Insulated	2x4 S-P-F	EPS	6.5	$14.00	$13.60	$20.40
Split-Insulated	2x4 S-P-F	XPS	5	$15.90	$15.40	$21.80
Split-Insulated	2x4 S-P-F	MFI	6	$15.40	$15.00	$32.60
Split-Insulated	2x4 S-P-F	PIC	7	$17.60	$17.20	$27.00
Split-Insulated	*2x6 S-P-F*	*EPS*	*10*	*$18.00*	*$16.90*	*$26.00*
Split-Insulated	*2x6 S-P-F*	*XPS*	*8*	*$21.60*	*$20.50*	*$29.30*
Split-Insulated	*2x6 S-P-F*	*MFI*	*9.5*	*$21.50*	*$20.40*	*$47.20*
Split-Insulated	*2x6 S-P-F*	*PIC*	*11.5*	*$25.00*	*$23.90*	*$38.60*
Exterior Insulated	2x4 S-P-F	EPS	8	$14.20	$14.00	$20.60
Exterior Insulated	2x4 S-P-F	XPS	6.5	$17.80	$17.60	$24.20
Exterior Insulated	2x4 S-P-F	MFI	7.5	$16.90	$16.80	$37.20
Exterior Insulated	2x4 S-P-F	PIC	9	$19.70	$19.50	$30.50

TABLE C-6 – TOTAL WALL COST PER EFFECTIVE R-VALUE FOR WHITEHORSE,YT, YELLOWKNIFE, NT, AND RESOLUTE BAY, NU, OF NORTHERN R-40 AND R-65+ WALL ASSEMBLIES

Wall Type	Framing	Primary Insulation	Effective R-value at -20°C	White Horse Cost ($/sf per effective R-value)	Yellowknife Cost ($/sf per effective R-value)	Resolute Cost ($/sf per effective R-value)
Double-stud wall	2x4 S-P-F	Cellulose	41	$0.37	$0.36	$0.66
Double-stud wall	2x4 S-P-F	Fiberglass	42	$0.21	$0.21	$0.33
Double-stud wall	2x4 S-P-F	ocSPF	40	$0.47	$0.48	$0.84
Double-stud wall	2x4 S-P-F	ccSPF	40	$0.50	$0.47	$0.73
SIPS	SIPS	EPS	40	$0.45	$0.46	$0.72
Split-Insulated	2x4 S-P-F	EPS	43	$0.32	$0.31	$0.47
Split-Insulated	2x4 S-P-F	XPS	43	$0.37	$0.36	$0.51
Split-Insulated	2x4 S-P-F	MFI	43	$0.36	$0.35	$0.76
Split-Insulated	2x4 S-P-F	PIC	42	$0.42	$0.41	$0.64
Split-Insulated	*2x6 S-P-F*	*EPS*	*66*	*$0.27*	*$0.26*	*$0.40*
Split-Insulated	*2x6 S-P-F*	*XPS*	*67*	*$0.32*	*$0.31*	*$0.44*
Split-Insulated	*2x6 S-P-F*	*MFI*	*66*	*$0.33*	*$0.31*	*$0.72*
Split-Insulated	*2x6 S-P-F*	*PIC*	*67*	*$0.37*	*$0.36*	*$0.57*
Exterior Insulated	2x4 S-P-F	EPS	41	$0.35	$0.34	$0.51
Exterior Insulated	2x4 S-P-F	XPS	42	$0.42	$0.41	$0.57
Exterior Insulated	2x4 S-P-F	MFI	41	$0.42	$0.41	$0.92
Exterior Insulated	2x4 S-P-F	PIC	41	$0.48	$0.47	$0.74

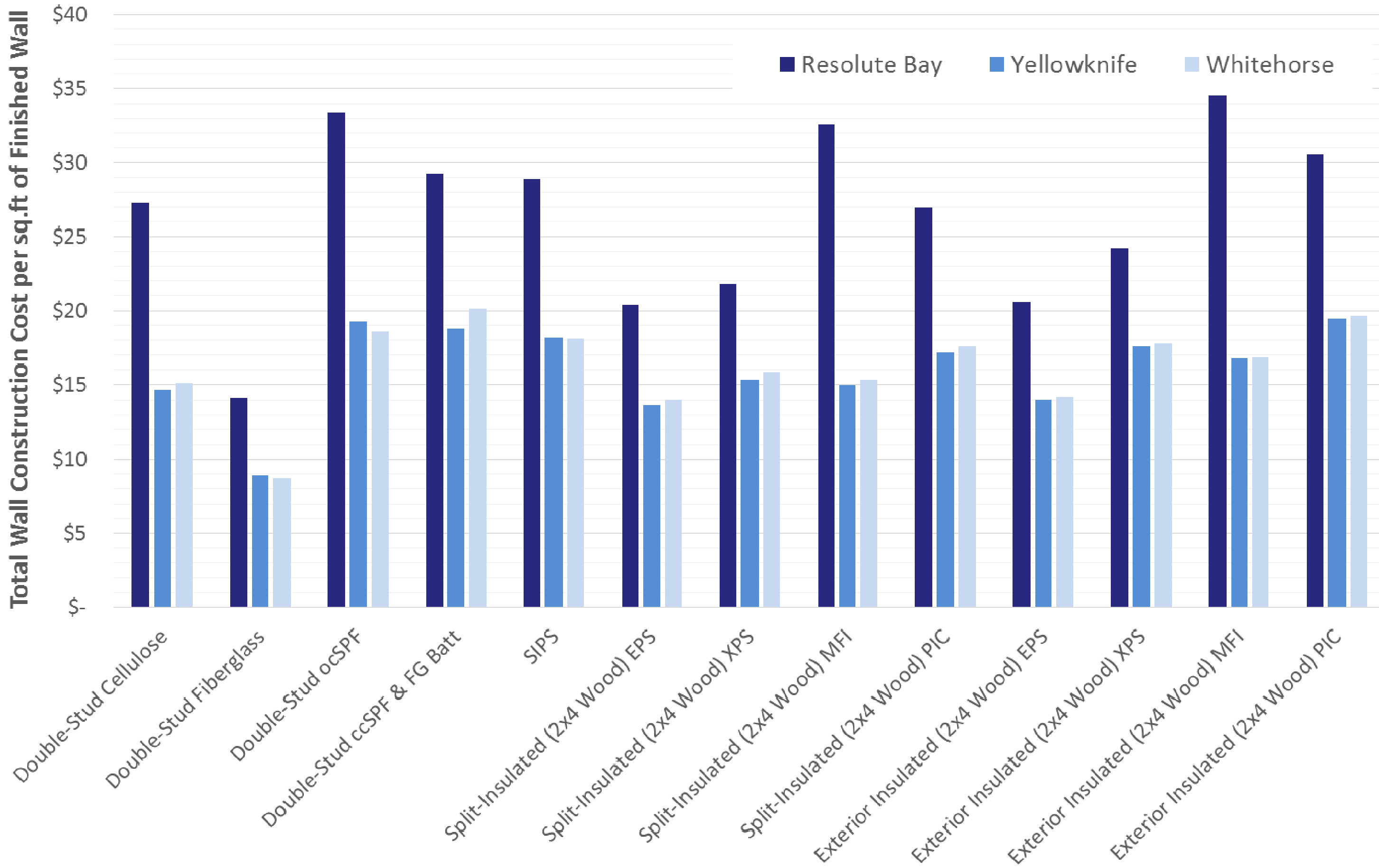


Figure C-2 – Cost Comparison of Candidate R-40 Wall Types for Resolute Bay, Yellowknife, and Whitehorse

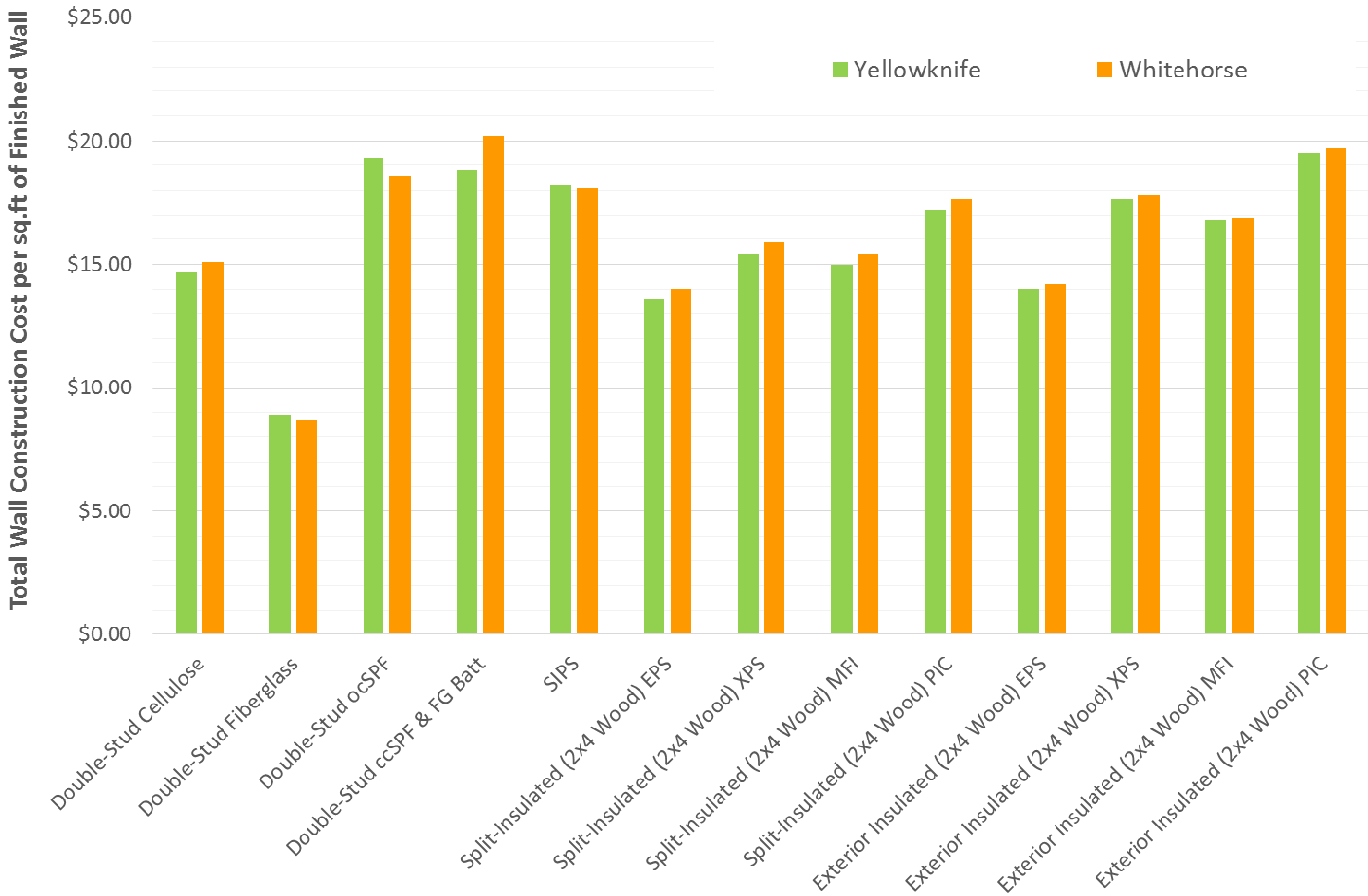


Figure C-3 – Cost Comparison of Candidate R-40 Wall Types for Yellowknife, and Whitehorse

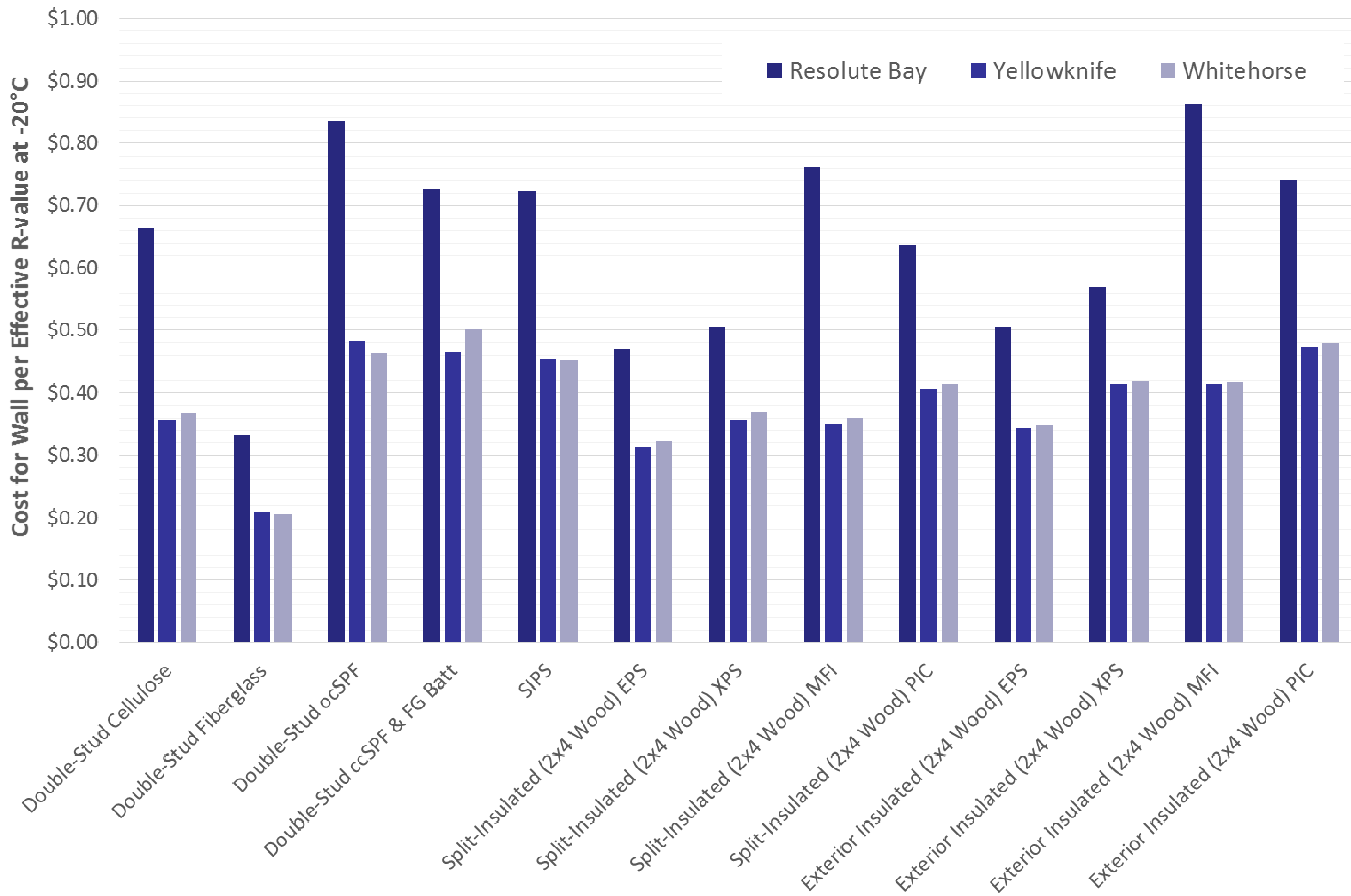


Figure C-4 – Cost Comparison of Candidate R-40 Wall Types Per Effective R-value for Resolute Bay, Yellowknife, and Whitehorse

A breakdown of the cost components for the ~R-40 wall assemblies in Resolute Bay, NU, are included in Figure C-5. These costs separate the shipping, labour, and material costs. Labour and material costs for Yellowknife and Whitehorse are provided in Figure C-6 and Figure C-7 respectively for comparison.

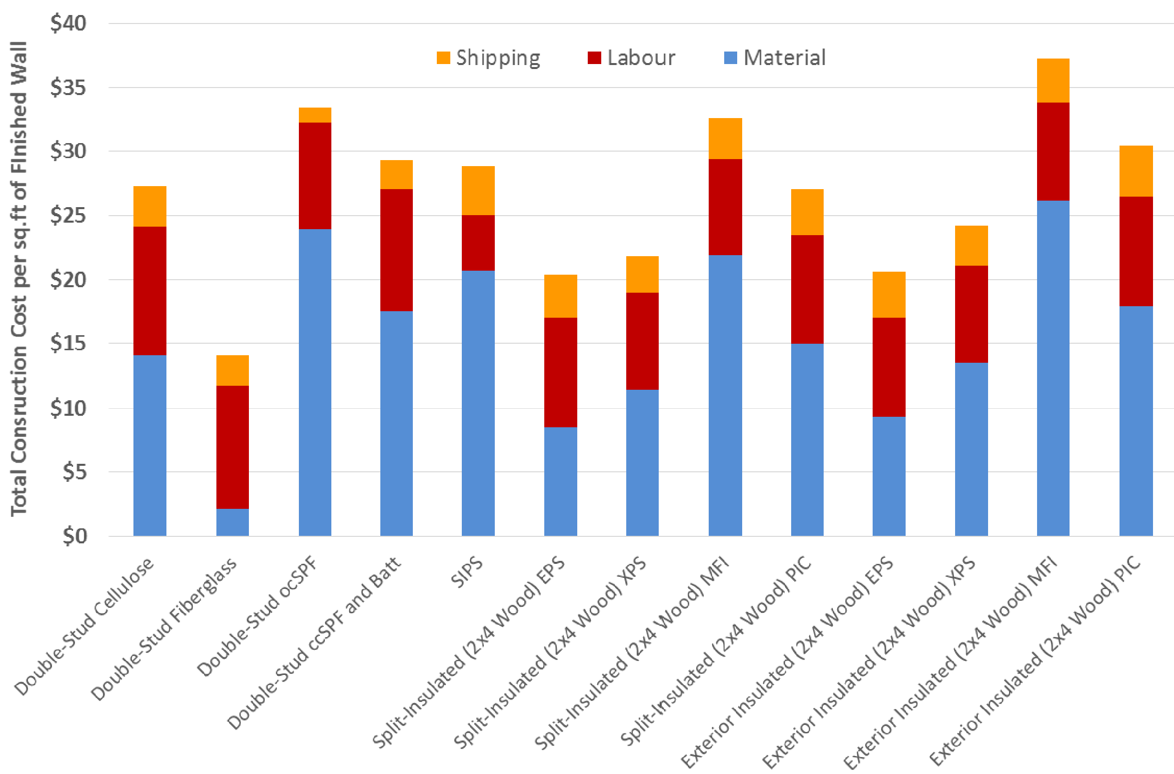


Figure C-5 – Cost Breakdown of R-40 wall options for Shipping, Labour, and Material Costs per Square Foot of Wall Assembly in Resolute Bay, NU

In most wall assemblies, labour costs comprise the largest component. The results are therefore sensitive to the local labour rates and some local variations may exist. In location where labour is more expensive, wall assemblies with a lower labour requirements will perform even better than others. Variations to shipping costs may be anticipated, depending on location and distance. However, shipping fees for remote communities is a smaller component of the total cost, and therefore the costing conclusions are not as susceptible to variation. The exception is transportation of specialized equipment, such as sprayfoam or blown cellulose installation equipment. While efforts have been undertaken to assess a cost to ship the equipment to site and return, some variations to actual costs may exist. Similarly, labour costs for installation of specialized insulations may not be adequately captured by the costing exercise.

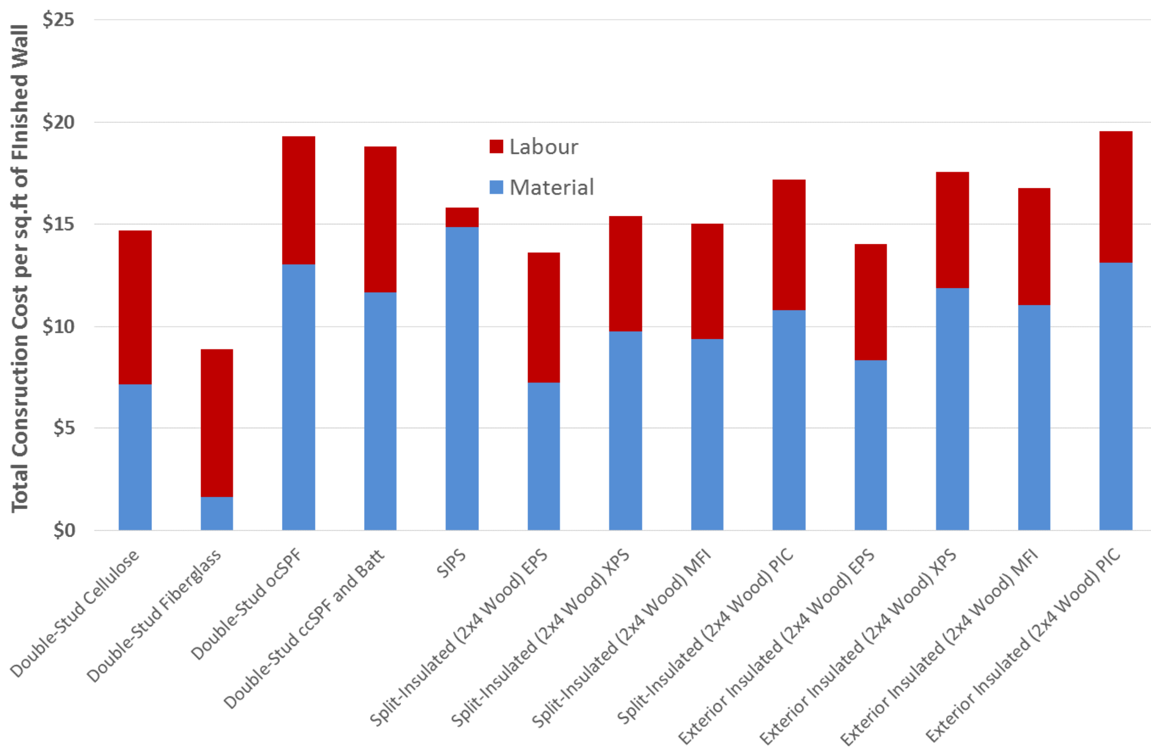


Figure C-6 – Cost Breakdown of R-40 wall options for Labour, and Material Costs per Square Foot of Wall Assembly in Yellowknife, NT

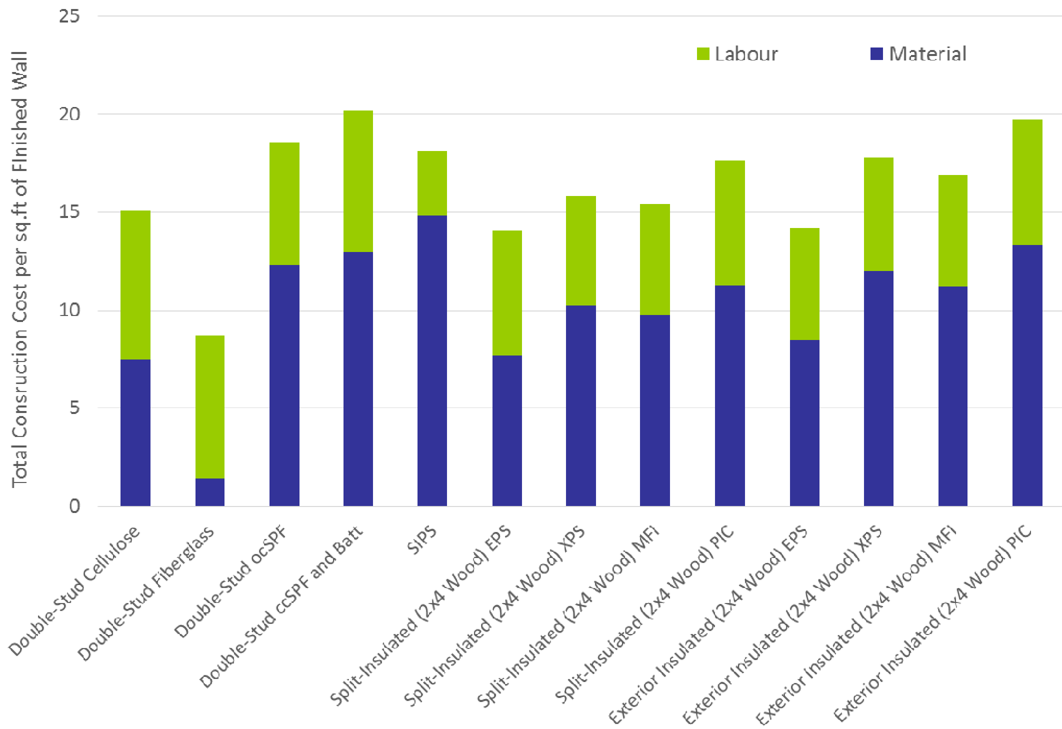


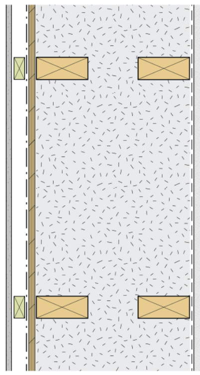
Figure C-7 – Cost Breakdown of R-40 wall options for Labour and Material Costs per Square Foot of Wall Assembly in Whitehorse, YT

Appendix D -
Wall Type Evaluation Charts

Appendix D – Wall Performance Summary

This section discusses the performance of the candidate wall assemblies. It also includes pertinent details on construction, material selection, and nominal and effective R-values. Each respective assembly includes the scoring results for the candidate walls and includes notes affecting the respective scores.

D-CFI	Double-Stud Wall with Dense-pack Cellulose Fibre Insulation



- Cladding
- ½” Air Space
- Housewrap
- ½” Plywood
- Double 2x4 S-P-F stud framing (5” gap between plates)
- 13.5” of Dense-pack Cellulose Insulation
- Polyethylene Air/Vapour Barrier
- ½” Gypsum Drywall

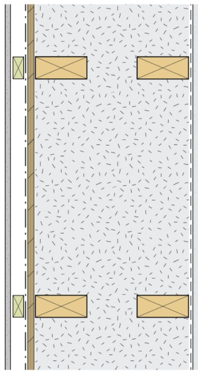
* Note that the polyethylene sheet is often placed to the exterior of the inner stud wall to protect from damage

Structure:	Double 2x4 stud framed wall; exterior framing sheathed with plywood. Interior 2x4 stud wall load bearing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails, edges taped.	
	Air	Polyethylene sheet, installed behind GWB, sealed with acoustic sealant and tape at all seams and penetrations. Internal cavity convection suppressed by dense-pack cellulose	
	Vapour	Interior polyethylene vapour barrier	
	Heat	13.5” dense-pack cellulose insulation, to 3.5-4.0 pcf. @ R-3.6/inch at FTC @ R-4.3/inch at -20˚C mean	
		R-value at 25˚C	48.7 Nominal 38.4 Effective
		R-value at -20˚C	57.8 Nominal 41.1 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Hygrothermal Durability	**Fail**	Susceptible to air leakage condensation
Thermal Performance	Good	Clear-wall performance minimizes thermal bridging, however thermal bridging though wood framing.
Constructability:	Poor to Moderate	Air sealing detailing and double-stud wall requires extra labour. Dense-pack cellulose requires specialized equipment.
Cost	Moderate	Construction of two framed walls requires extra material and labour.

D-FG Double-Stud Wall with Fiberglass Batt Insulation



- Cladding
- ½” Air Space
- Housewrap
- ½” Plywood
- Double 2x4 S-P-F stud framing (~7” gap between plates)
- 14” of Fiberglass Batt Insulation (3.5” R-13, ~7” R-28 and 3.5” R-13 batts)
- Polyethylene Air/Vapour Barrier
- ½” Gypsum Drywall

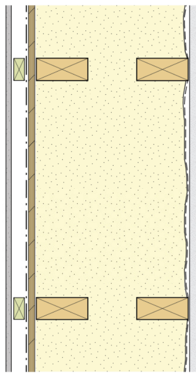
* Note that the polyethylene sheet is often placed to the exterior of the inner stud wall to protect from damage

Structure:	Double 2x4 stud framed wall; exterior framing sheathed with plywood. Interior 2x4 stud wall load bearing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails, edges taped.	
	Air	Polyethylene sheet, installed behind GWB, sealed with acoustic sealant and tape at all seams and penetrations.	
	Vapour	Interior polyethylene vapour barrier	
	Heat	14” fiberglass insulation, 3.5” and ~7” batts @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	51.8 Nominal 41.0 Effective
		R-value at -20˚C	56.0 Nominal 42.3 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Hygrothermal Durability	**Fail**	Susceptible to air leakage condensation
Thermal Performance	Good	Clear-wall performance minimizes thermal bridging, however thermal bridging though wood framing.
Constructability:	Moderate	Air sealing detailing and double-stud wall requires extra labour. Dense-pack cellulose requires specialized equipment.
Cost	Good	Construction of two framed walls requires extra material and labour, but low cost of fiberglass vs cellulose or sprayfoam compensates

D-ocSPF Double-Stud Wall with Open-Cell Spray Polyurethane Foam



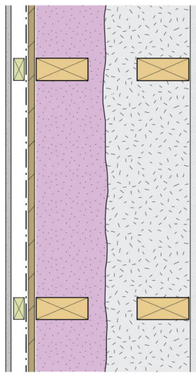
- Cladding
- ½” Air Space
- Housewrap
- ½” Plywood
- Double 2x4 S-P-F stud framing (3” gap between plates)
- 13” of ½ pcf open-cell SPF Insulation
- Polyethylene Air/Vapour Barrier
- ½” Gypsum Drywall

Structure:	Double 2x4 stud framed wall; exterior framing sheathed with plywood. Interior 2x4 stud wall load bearing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails, edges taped.	
	Air	The ½pcf open-cell SPF forms the primary air barrier. Ensure joints between framing (e.g. top and bottom plates) are air sealed with caulking.	
	Vapour	Interior polyethylene vapour barrier	
	Heat	13” ½ pcf open-cell spray polyurethane foam insulation @ R-3.6/inch at FTC @ R-4.5/inch at -20˚C mean	
		R-value at 25˚C	46.9 Nominal 36.6 Effective
		R-value at -20˚C	58.5 Nominal 40.0 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Provided no gaps/shrinkage in sprayfoam application.
Thermal Performance	Poor	Thermal bridging through the high R-value spray foam insulation reduces the effective R-value.
Constructability:	Poor	Installation of open-cell spray polyurethane foam requires special training and equipment.
Cost	Moderate	Construction of two framed walls requires extra material and labour and use of sprayfoam in remote Northern regions while relatively cheap to ship requires specialized equipment and trained labour and is expensive.

D-ccSPF	Double-Stud Wall with Closed-Cell Spray Polyurethane Foam



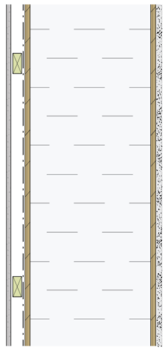
- Cladding
- ½” Air Space
- Housewrap
- ½” Plywood
- Double 2x4 S-P-F stud framing
- 5” of 2pcf Closed-cell SPF insulation
- ~7” Fiberglass Batts
- ½” Gypsum Drywall

Structure:	Double 2x4 stud framed wall; exterior framing sheathed with plywood. Interior 2x4 stud wall load bearing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails	
	Air	The 2pcf closed-cell SPF forms the primary air barrier. Ensure joints between framing (e.g. top and bottom plates) are air sealed with caulking.	
	Vapour	5” of 2pcf closed-cell SPF. An additional polyethylene vapour barrier at the interior is not recommended.	
	Heat	5” 2 pcf closed-cell spray polyurethane foam insulation @ R-6.0/inch at FTC @ R-7.1/inch at -20˚C mean 7” fiberglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	55.3 Nominal 38.2 Effective
		R-value at -20˚C	60.7 Nominal 40.3 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Provided no gaps/shrinkage in sprayfoam application.
Thermal Performance	Poor	Thermal bridging through the high R-value spray foam insulation reduces the effective R-value.
Constructability:	Poor	Special training and equipment is required to install the two insulations.
Cost	Moderate	Construction of two framed walls requires extra material and labour and use of sprayfoam in remote Northern regions while relatively cheap to ship requires specialized equipment and trained labour and is expensive. Use of fiberglass batts instead of completely filling the cavity with sprayfoam reduces the costs

SIPS	Structural Insulated Panel



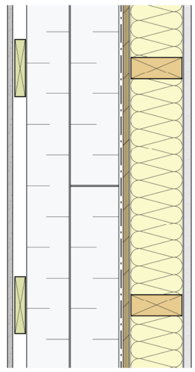
- Cladding
- ½" Air Space
- Housewrap
- Structural Insulated Panel with 8" of EPS insulation
- ½" Gypsum Drywall

Structure:	Structural insulated panel		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails, edges taped.	
	Air	The SIPS functions as the air barrier, with joints sealed with caulking and single component sprayfoam	
	Vapour	Interior OSB sheathing and EPS foam	
	Heat	8" expanded polystyrene insulation @ R-4.0/inch at FTC @ R-4.9/inch at -20˚C mean	
		R-value at 25˚C	32.0 Nominal 32.0 Effective
		R-value at -20˚C	40.0 Nominal 40.0 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Careful attention to air sealing at penetrations and around the panel edges is critical.
Thermal Performance	Excellent	Minimal thermal bridging at the spline connections between the panels.
Constructability:	Moderate	Decreased construction times are achieved by panelization, but installation of the panels is difficult due to size and weight.
Cost	Poor	Panels are expensive and the equipment and labour to erect and assemble is specialized

S4-EPS EPS Split Insulated Wall Assembly on 2x4 Framed Wall



- Cladding
- ½” Air Space
- 6.5” EPS
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing with R-13 Fibreglass Batt
- ½” Gypsum Drywall

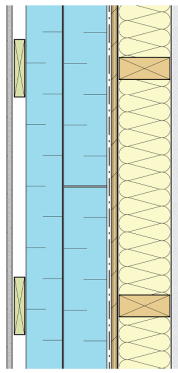
<table>
<tr><td>Structure:</td><td colspan="3">2x4 stud framing with plywood or OSB sheathing.</td></tr>
<tr><td rowspan="6">Control</td><td>Precipitation</td><td colspan="2">Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.</td></tr>
<tr><td>Air</td><td colspan="2">Taped sheathing (or alternately taped sheathing membrane)</td></tr>
<tr><td>Vapour</td><td colspan="2">The sheathing operates as the vapour control layer.

An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.</td></tr>
<tr><td rowspan="3">Heat</td><td colspan="2">6.5” expanded polystyrene insulation
@ R-4.0/inch at FTC
@ R-4.9/inch at -20˚C mean
3.5” fibreglass batt insulation
@ R-3.7/inch at FTC
@ R-4.0/inch at -20˚C mean</td></tr>
<tr><td>R-value at 25˚C</td><td>39.0 Nominal
37.6 Effective</td></tr>
<tr><td>R-value at -20˚C</td><td>44.9 Nominal
43.5 Effective</td></tr>
</table>

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Excellent	Attention to the optimization of cladding attachment fasteners is required.
Constructability:	Excellent	Attention to wall penetration detailing is required.
Cost	Excellent	The high cold-weather performance of the EPS requires less material than other walls. EPS is readily available from most suppliers in the North

S4-XPS	XPS Split Insulated Wall Assembly on 2x4 Framed Wall



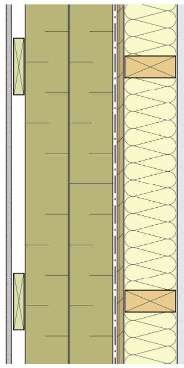
- Cladding
- ½" Air Space
- 5" XPS
- Housewrap
- ½" Plywood
- 2x4 S-P-F stud framing with R-13 Fibreglass Batt
- ½" Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.	
	Heat	5" extruded polystyrene insulation @ R-5.0/inch at FTC @ R-6.3/inch at -20°C mean 3.5" fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20°C mean	
		R-value at 25°C	37.9 Nominal 36.5 Effective
		R-value at -20°C	44.5 Nominal 43.1 Effective

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Excellent	Attention to the optimization of cladding attachment fasteners is required.
Constructability:	Excellent	Attention to wall penetration detailing is required.
Cost	Excellent	The high cold-weather performance of the XPS requires less material than other walls.

S4-MFI	MFI Split Insulated Wall Assembly on 2x4 Framed Wall



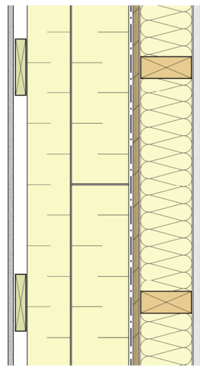
- Cladding
- ½" Air Space
- 6" Mineral Fibre Insulation (8 pcf density)
- Housewrap
- ½" Plywood
- 2x4 S-P-F stud framing with R-13 Fibreglass Batt
- ½" Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. Alternately a polyethylene vapour barrier may be installed at the interior without issue (unlike exterior foam).	
	Heat	6" semi-rigid mineral fibre insulation @ R-4.0/inch at FTC @ R-5.2/inch at -20˚C mean 3.5" fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	37.0 Nominal 35.6 Effective
		R-value at -20˚C	44.2 Nominal 42.8 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Excellent	Attention to the optimization of cladding attachment fasteners is required.
Constructability:	Excellent	Attention to wall penetration detailing is required.
Cost	Good	The high cold-weather performance of the mineral fibre requires less material than some other insulation types though the weight is greater than foam insulation and more expensive to ship.

S4-PIC	PIC Split Insulated Wall Assembly on 2x4 Framed Wall



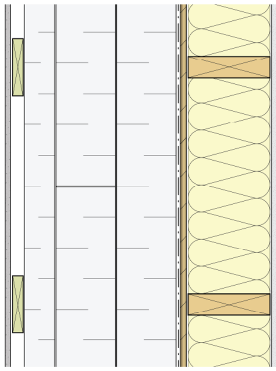
- Cladding
- ½” Air Space
- 7” Polyisocyanurate insulation
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing with R-13 Fibreglass Batt
- ½” Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.	
	Heat	7” polyisocyanurate insulation @ R-6.0/inch at FTC @ R-4.4/inch at -20˚C mean 3.5” fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	55.1 Nominal 53.7 Effective
		R-value at -20˚C	43.8 Nominal 42.4 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Moderate	Exterior insulation helps minimizes thermal bridging, but poor cold-weather performance of polyisocyanurate insulation requires significant thickness to compensate
Constructability:	Good	Careful wall penetration detailing is required due to the thicker exterior insulation. Longer fasteners required with polyisocyanurate than other insulation types.
Cost	Good	The poor cold-weather performance of the polyisocyanurate requires more material than other insulation types.

S6-EPS	EPS Split Insulated Wall Assembly on 2x6 Framed Wall



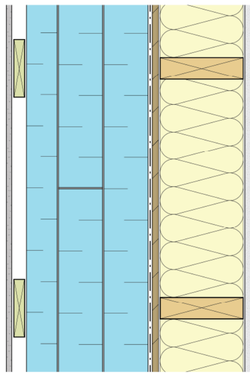
- Cladding
- ½” Air Space
- 10” EPS
- Housewrap
- ½” Plywood
- 2x6 S-P-F stud framing with R-21 Fibreglass Batt
- ½” Gypsum Drywall

Structure:	2x6 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.	
	Heat	10” expanded polystyrene insulation @ R-4.0/inch at FTC @ R-4.9/inch at -20˚C mean 5.5” fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	61.1 Nominal 56.7 Effective
		R-value at -20˚C	70.0 Nominal 65.6 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Moderate	Control of interior air leakage condensation requires significant exterior insulation, resulting in effective R-value greater than the required R-40.
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation. 10” thick exterior insulation requires longer fasteners.
Cost	Moderate	Requires more exterior insulation that with 2x4s to control interior air leakage condensation.

S6-XPS	XPS Split Insulated Wall Assembly on 2x6 Framed Wall



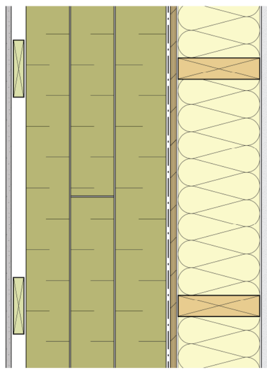
- Cladding
- ½” Air Space
- 8” XPS
- Housewrap
- ½” Plywood
- 2x6 S-P-F stud framing with R-21 Fibreglass Batt
- ½” Gypsum Drywall

Structure:	2x6 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.	
	Heat	8” extruded polystyrene insulation @ R-5.0/inch at FTC @ R-6.3/inch at -20˚C mean 3.5” fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	61.1 Nominal 56.7 Effective
		R-value at -20˚C	71.4 Nominal 67.0 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Moderate	Control of interior air leakage condensation requires significant exterior insulation, resulting in effective R-value greater than the required R-40.
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation. 8” thick exterior insulation requires longer fasteners.
Cost	Good	Requires more exterior insulation that with 2x4s to control interior air leakage condensation.

S6-MFI	MFI Split Insulated Wall Assembly on 2x6 Framed Wall



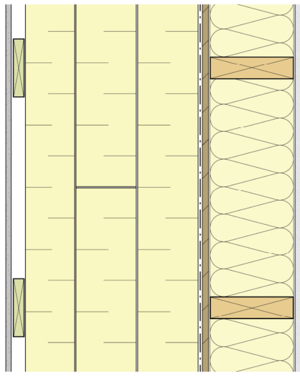
- Cladding
- ½” Air Space
- 9.5” Mineral Fibre Insulation
- Housewrap
- ½” Plywood
- 2x6 S-P-F stud framing with R-21 Fibreglass Batt
- ½” Gypsum Drywall

Structure:	2x6 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. Alternately a polyethylene vapour barrier may be installed at the interior without issue (unlike exterior foam).	
	Heat	9.5” semi-rigid mineral fibre insulation @ R-4.0/inch at FTC @ R-5.2/inch at -20˚C mean 3.5” fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	59.1 Nominal 54.7 Effective
		R-value at -20˚C	70.4 Nominal 66.0 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Moderate	Control of interior air leakage condensation requires significant exterior insulation, resulting in effective R-value greater than the required R-40.
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation. 9.5” thick exterior insulation requires longer fasteners.
Cost	Good	Requires more exterior insulation that with 2x4s to control interior air leakage condensation. Weight of mineral fiber is greater than foam insulation.

S6-PIC PIC Split Insulated Wall Assembly on 2x6 Framed Wall



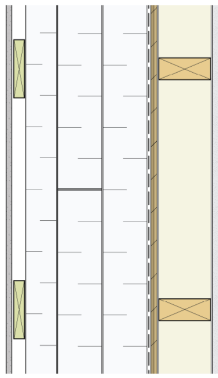
- Cladding
- ½” Air Space
- 11.5” Polyisocyanurate insulation
- Housewrap
- ½” Plywood
- 2x6 S-P-F stud framing with R-21 Fibreglass Batt
- ½” Gypsum Drywall

Structure:	2x6 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer. An interior polyethylene vapour barrier is not recommended otherwise a double vapour barrier situation will be created.	
	Heat	11.5” polyisocyanurate insulation @ R-6.0/inch at FTC @ R-4.4/inch at -20˚C mean 3.5” fibreglass batt insulation @ R-3.7/inch at FTC @ R-4.0/inch at -20˚C mean	
		R-value at 25˚C	90.1 Nominal 85.7 Effective
		R-value at -20˚C	71.6 Nominal 67.2 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from humidity
Thermal Performance	Poor	Exterior insulation helps minimizes thermal bridging, but poor cold-weather performance of polyisocyanurate insulation requires significant thickness to compensate
Constructability:	Good	Careful wall penetration detailing is required due to the exterior insulation. 11.5” of insulation requires very long fasteners for cladding attachment.
Cost	Poor	Requires more exterior insulation that with 2x4s to control interior air leakage condensation. The poor cold-weather performance of polyiso requires more material than other insulation types.

X-EPS Exterior EPS Insulation on 2x4 Framed Wall



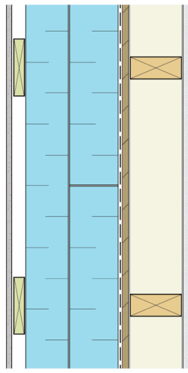
- Cladding
- ½” Air Space
- 8” EPS
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing
- ½” Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer	
	Heat	8” expanded polystyrene insulation @ R-4.0/inch at FTC @ R-4.9/inch at -20˚C mean	
		R-value at 25˚C	32.0 Nominal 33.6 Effective
		R-value at -20˚C	39.2 Nominal 40.7 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from interior humidity
Thermal Performance	Excellent	
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation.
Cost	Excellent	Large thicknesses of insulation result in higher shipping and labour costs, but the high performance and low cost of EPS compensates.

X-XPS	Exterior XPS Insulation on 2x4 Framed Wall



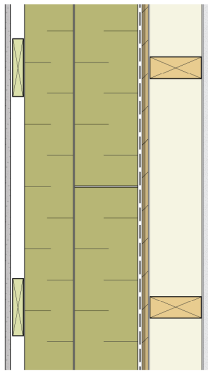
- Cladding
- ½” Air Space
- 6.5” XPS
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing
- ½” Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer	
	Heat	6.5” extruded polystyrene insulation @ R-5.0/inch at FTC @ R-6.3/inch at -20˚C mean	
		R-value at 25˚C	32.3 Nominal 33.9 Effective
		R-value at -20˚C	41.0 Nominal 42.5 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from interior humidity
Thermal Performance	Excellent	
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation.
Cost	Excellent	Large thicknesses of insulation result in higher shipping and labour costs, but the high performance and lower cost of XPS compensates.

X-MFI	Exterior MFI Insulation on 2x4 Framed Wall



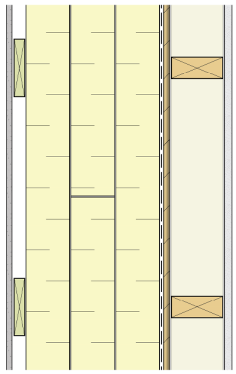
- Cladding
- ½” Air Space
- 7.5” MFI
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing
- ½” Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer	
	Heat	7.5” semi-rigid mineral fibre insulation @ R-4.0/inch at FTC @ R-5.2/inch at -20˚C mean	
		R-value at 25˚C	30.0 Nominal 31.6 Effective
		R-value at -20˚C	39.0 Nominal 40.5 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from interior humidity
Thermal Performance	Excellent	
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation.
Cost	Good.	Large thicknesses of insulation result in higher shipping and labour costs, but the high performance and lower cost of MFI compensates. Weight of mineral fiber increases shipping cost to remote regions.

X-PIC	Exterior PIC Insulation on 2x4 Framed Wall



- Cladding
- ½” Air Space
- 9” PIC
- Housewrap
- ½” Plywood
- 2x4 S-P-F stud framing
- ½” Gypsum Drywall

Structure:	2x4 stud framing with plywood or OSB sheathing.		
Control	Precipitation	Rain-screen cavity with housewrap installed against sheathing, fastened with capnails.	
	Air	Taped sheathing (or alternately taped sheathing membrane)	
	Vapour	The sheathing operates as the vapour control layer	
	Heat	9” polyisocyanurate insulation @ R-6.0/inch at FTC @ R-4.4/inch at -20˚C mean	
		R-value at 25˚C	54.1 Nominal 55.6 Effective
		R-value at -20˚C	39.6 Nominal 41.1 Whole Assembly

PERFORMANCE RATINGS

Performance	Rating	Notes
Durability/Hygrothermal	Pass	Exterior insulation at the prescribed levels protects the walls from interior humidity
Thermal Performance	Moderate	Exterior insulation helps minimizes thermal bridging, but poor cold-weather performance of polyisocyanurate insulation requires significant thickness to compensate
Constructability:	Good	Careful wall penetration detailing is required due to the thick exterior insulation.
Cost	Moderate	The poor cold-weather performance of the polyisocyanurate requires more material than other insulation types.