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Prefabricated Exterior Energy Retrofit (PEER) Project Guide

Canada

"CanmetENERGY- Ottawa leads the development of energy science and technology solutions for the environmental and economic benefit of Canadians."

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Funding for this work was provided by Natural Resources Canada through the Program of Energy Research and Development and Energy Innovation Program.

Cat. No. M154-153/2023E-PDF

ISBN 978-0-660-48179-1

ACKNOWLEDGEMENTS

Technical content of this Guide was developed by Mark Carver and Christopher McLellan of Natural Resources Canada, CanmetENERGY, Daniel Calero and Graham Finch, P.Eng of RDH, Jeff Armstrong of Cold Climate Building and Darcy Charlton of If Then Architecture.

The authors wish to thank all those who contributed and assisted with the review, editing and development of this Guide, including Brock Conley of CanmetENERGY, Peter Amerongen of ReNü Engineering, Glenn Somerton, P.Eng and Vusal Ibrahimli, E.I.T. of Morrison Hershfield.

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1. OVERVIEW

1.1 What is this guide and who is it for?

This document provides builders, panel fabricators, design consultants and building capture specialists with step-by-step guidance to carry-out prefabricated (panelized) exterior retrofits, with a focus on improving the energy performance of existing housing. It covers pre-design, building measurement (building capture), panel design, fabrication, and installation processes. The guide walks step-by-step, from project conception through to project completion, while discussing considerations at various stages. Others interested in this approach may include building owners, policy makers, building officials, suppliers, and energy advisors.

It is still early in the development of industrialized approaches to upgrade the energy performance of existing housing. The information and insights contained in this Guide are based on a small sample of real-world projects and thus should not be viewed as definitive, but as guidance that will evolve as new projects are completed and experience is gained.

1.2 Scope

This version is limited to prefabricated, above-grade wall retrofits of Part 9 buildings (Housing and Small Buildings) under the National Building Code of Canada (NBC). The intended building typology is multi-family low-rise, though the general concepts may be applicable anywhere from single-family housing to large buildings. The implications of wall retrofits on other enclosure elements such as foundations and roofs, and mechanical and electrical systems are discussed but these other elements are not the focus of this guide.

1.3 What is PEER?

Prefabricated Exterior Energy Retrofit (PEER) was a six-year (2016-2022) research and development project conducted by CanmetENERGY. The project sought to develop a process as well as panel designs for Energiesprong-style [1] projects, adapted for the Canadian housing stock and industry. PEER R&D was focussed on the development of retrofit wall panels. This Guide will touch on all aspects of a deep retrofit including below grade, roofs, and mechanicals, but the focus is on above grade wall assemblies.

The process involves scanning or imaging a building to capture all relevant dimensions, designing custom-fit wall panels to reclad the building, fabricating these panels off-site, and installing them on the building.

At the time of publication, the PEER project has developed five prototype wall panel designs and three documented pilot projects have been completed in Canada. To maximize the benefits of off-site construction, PEER envisions that panels will be factory finished as much as is practical. Panels include pre-installed structural support and attachments; thermal insulation; air, vapour and water control membranes and flashings; fenestration and rainscreen claddings. The thermal resistance and airtightness targets are consistent with net-zero energy and passive house performance. Durability, including the proper control of water and vapour over existing walls are paramount to the overall building enclosure design.

1.4 The case for upgrading the building enclosure of existing housing

There are several reasons to upgrade the building enclosure of the existing Canadian housing stock:

1. To reduce heating demand, operational emissions, and energy costs,
2. To improve comfort, thermal resilience, and passive survivability,
3. To improve the building's durability and resilience to severe weather and a changing climate,
4. To reduce the risk of condensation and associated mold growth, improve aesthetics, increase property value, and to replace obsolete and aged siding and fenestration systems.

1.4.1 Reducing greenhouse gas emissions

The Canadian residential sector accounts for more than one-sixth of national energy use and close to 14% of Canada's energy related GHG emissions. Within this sector, space heating represents two-thirds of the GHG emissions. By retrofitting the older or the more inefficient Canadian houses to net-zero or passive house insulation levels and airtightness, heating demand can be reduced by 80% or more [2], [3]. All else being equal, reducing heating demand reduces emissions, and makes switching to less emissions-intensive (but often more costly) fuel sources more economically viable.

Governments of all levels have made commitments to reducing emissions. The Government of Canada has established targets to reduce emissions by 40-45% from 2005 levels by 2030 and to achieve net-zero emissions economy-wide by 2050. [4]

The Government of British Columbia, as a provincial leader on climate change action, has set a target to reduce emissions in buildings and communities by more than half by 2030 [5].

The Federation of Canadian Municipalities notes that municipalities have control over 50% of Canadian emissions. Further, some 516 municipalities across Canada have declared a climate emergency, with many developing or implementing local strategies to reduce emissions. [6]

While the motivation to reduce emissions is apparent and progress is being made, overall building sector emissions are trending upward. GHG emissions in residential, commercial, and institutional buildings accounted for 77 Mt CO2e in 2019, a 9.5% increase since 1990. By contrast, the emissions from residential buildings shows a different trend. Despite a projected emissions increase of 24.1 MT from 1990 to 2019 due to increased population and per capita floor space, residential buildings experienced a net reduction of 1.6 Mt CO2e through improved energy efficiency. [7]

To achieve a net reduction means that existing buildings are reducing emissions through fuel switching (from fossil fuel heating to electricity), energy efficiency, or stock replacement. As current building codes and regulations drive new construction towards net-zero energy, and potential future codes specifically address emissions, it is apparent that existing buildings, in particular the older inefficient stock, will have the greatest opportunity for emissions reduction.

Changing the paradigm and dramatically driving down emissions from this sector will require a new, industrialized approach to retrofit, geared for the community scale. PEER is aimed squarely at addressing this need.

Ottawa Community Housing completed a PEER pilot to retrofit four townhomes to net-zero energy and carbon in 2021. The project is expected to avoid 18 t of CO2e, (4-5 t, per unit) annually. The project contributed about 36 t CO2e in upfront material emissions during construction. If the project achieves its performance target of net-zero annual energy use, the GHG payback will be about two years. Extrapolating these impacts suggests that by retrofitting Canada's existing stock of 100,000+ similar, subsidized row-home housing units to zero carbon could mitigate from 0.5 Mt to 1.0 Mt CO2e annually or 10 to 20 Mt CO2e by 2050. For context, as noted above, emissions from the buildings sector were 77 Mt CO2e in 2019 [7].

1.4.2 Reducing energy costs

Space heating accounts for the largest share of energy use in the residential sector, as illustrated in Figure 1-1. Therefore, reducing heat loss through the envelope provides a significant opportunity to reduce energy costs. In 2019, the Canadian average household expenditure on energy for all home types was $2102 [8]. Given that space heating accounts for 61.6% of residential energy consumption, this results in an average cost of approximately $1295 per household for space heating.

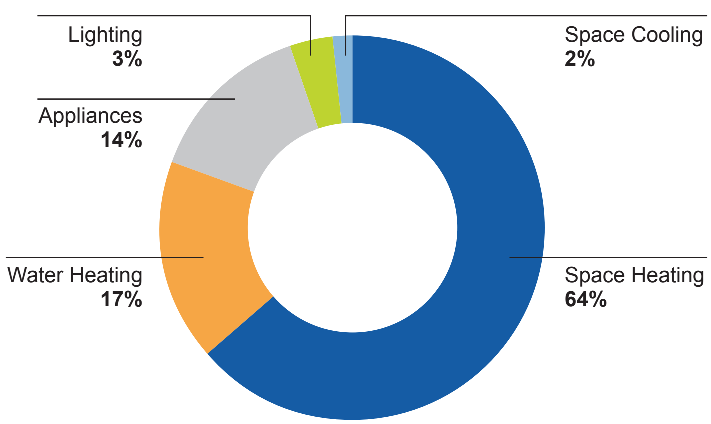

Figure 1-1: Distribution of residential energy use by end use, 2018 [9].

Families with low or moderate incomes can experience high home energy cost burdens (also known as energy poverty), which is defined as 6% or more of after-tax income spent on home energy. In Canada, 2.8 million households experience high home energy cost burdens, and of these 1.1 million are defined as low-income households (as determined using the after-tax low-income measure (LIM-AT)). Given there are 2.4 million low-income households, almost half of the low-income households experience high home energy cost burden, as shown in Figure 1-2. [10]

A number of factors, including the age, type, and size of home, can dictate energy costs. As shown in Figure 1-3, not surprisingly, the highest percentage of households experiencing high home energy burden live in dwellings constructed in 1960 or earlier. Energy burden declines in the more recent vintages.

There are approximately 550,000 subsidized housing units in Canada (100,000 of these are row dwellings, and 411,000 are apartments) [12]. While some social housing was built in the 1950's and war-worker housing in the decade prior, most social housing was built from 1964 through the 1980's [11].This vintage of housing also has over 20% of households experiencing a high home energy burden, with the rate likely being considerably higher in social housing. Much of the social housing stock is in poor condition due to deferred maintenance and lack of funding. While the simple architectural form of most social housing, and the large portfolios of housing providers, lends itself well to the PEER approach, reducing energy costs for the occupants provides a social benefit by alleviating the energy burden.

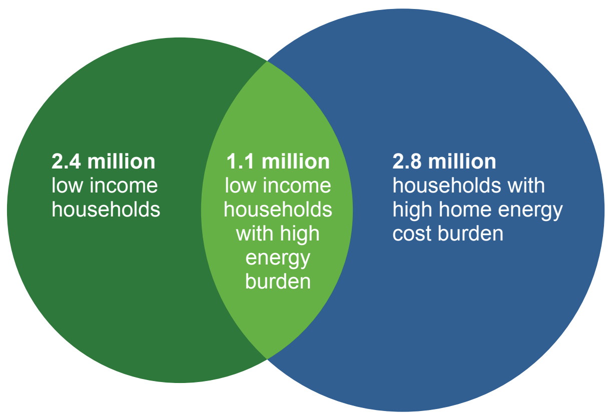

Figure 1-2: Households in Canada, categorized by low-income (LIM_AT) and high home energy cost burden (6%+ of after-tax income spent on home energy) status [10].

Energy costs for the four Ottawa Community Housing units were about $2200/year prior to the retrofit. Although they will still pay a monthly fee to be connected to the electricity grid, tenants are expected to save about $1850 per year in energy costs (85%) and be protected from future energy price escalation.

Table 1-1: Energy costs before and after a NZ PEER retrofit

Energy Cost Type	Existing Building	Net-Zero Retrofit
Electrical connection charge ($/yr)	344	344
Electrical consumption (kWh/yr)	7,440	0
Electricity consumption charge ($/yr)	1,072	0
Natural gas connection charge ($/yr)	258	0
Natural gas consumption (m3)	2,221	n/a
Natural gas consumption charge ($/yr)	533	0
Total annual energy cost ($/yr)	**2,207**	**334**

1.4.3 Improving comfort, resiliency and durability

High performance building enclosures provide benefits beyond reducing energy and emissions. Highly insulated and airtight homes enhance occupant comfort by reducing drafts, reducing temperature stratification, and reducing radiative losses through glazing.

Beyond comfort, high performance building enclosures improve the resiliency of homes. Climate change is increasing the severity and frequency of extreme weather events. These events often lead to power outages that may coincide with extremely cold or hot weather. High performance building enclosures contribute to better thermal resilience by passively maintaining comfortable and survivable conditions for longer during a power outage. Improved airtightness in conjunction with a properly designed and commissioned mechanical ventilation system allows for better control of indoor air quality, which can be particularly useful during significant air pollution events such as wildfire smoke.

Incorporating well designed and executed water management details into building enclosure retrofits improves the durability and resilience of the building to extreme weather events. As the thermal resistance of assemblies is increased, their drying potential may be reduced as there is less heat flow through them. It is critical therefore, to keep these assemblies from getting wet in the first place.

Adding insulated panels from the exterior, in addition to being less disruptive for occupants, keeps the existing framing members and sheathing warmer through the cold months. This reduces the risk of condensation that contributes to mould growth and associated health problems.

1.5 The case for a prefabricated approach to deep retrofits

To transform our housing stock to net-zero emission by mid-century, more than 500,000 homes would have to be retrofitted each year. Relative to new construction, that works out to two deep retrofits for every new housing start for the next 30 years.

Despite generous federal, provincial, and utility programs to encourage homeowners to invest in energy retrofits, the current approach falls short in both the rate and depth of interventions. Most retrofits completed to date have been “shallow” (i.e., less than 20% energy improvements).

There are several barriers to traditional deep retrofits as they are disruptive, expensive, and there is risk—both technical and financial. In addition, there is a lack of skilled trades in Canada able to perform this type of work at scale. Consequently, deep retrofits are rare. Currently, there is essentially zero market and no standardized solutions.

PEER is a process that can overcome these barriers, leading to large scale, rapid, deep retrofitting of Canadian homes. Digital scans of an existing building are taken to acquire dimensional data. Airtight, highly insulated cladding panels with new windows and doors are fabricated off-site, based on these scans. This off-site, prefab approach significantly reduces the amount of on-site work and associated disruptions for building occupants. Significant opportunity exists to automate the workflow from the digital capture, design, and fabrication of panels.

To realize the benefits of PEER at a scale to significantly reduce the emissions of the existing housing stock, a shift from one-off site work to mass customization will be required. This is a key challenge for an industry that is lagging in productivity gains, but also an opportunity for innovators to lead the industry.

Whereas other sectors such as manufacturing have observed eight-fold increases in productivity, construction productivity has remained stagnant over several decades [12].

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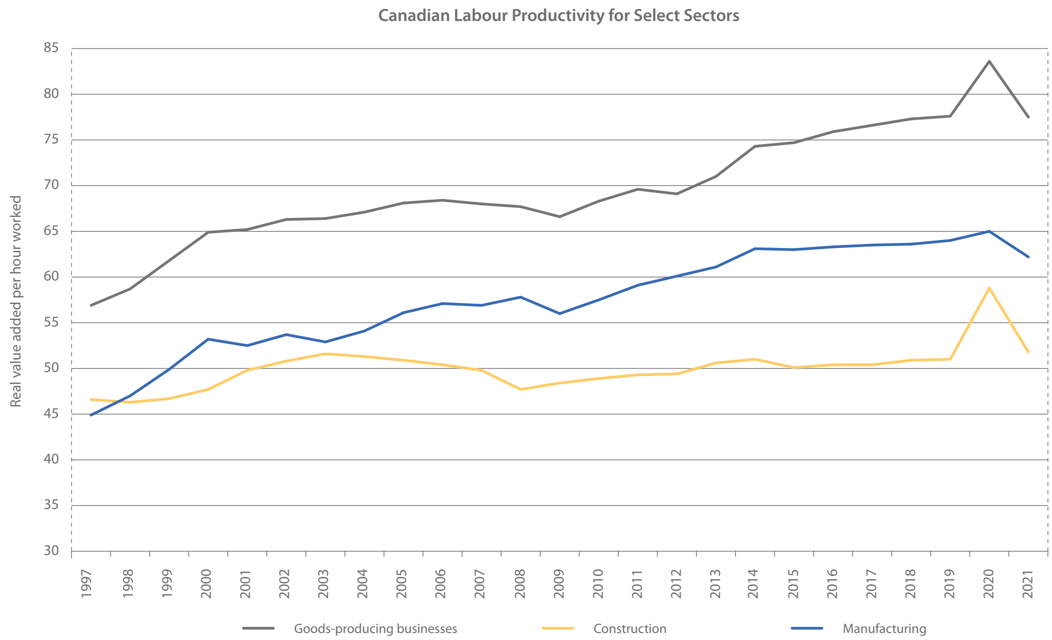


Figure 1-3: Labour-productivity growth in construction (yellow) falls far short of growth in manufacturing (blue) and all goods-producing businesses (grey) in Canada [3][1].

Prefabrication and automation are innovations that many in the industry look to for productivity improvements.

Other benefits of prefabrication include:

- Less disruption for residents because of reduced time on site;
- Less waste;
- Improved quality and worker satisfaction resulting from working indoors, at one location, in a comfortable, well-lit environment where tools are secure;
- Improved worker safety with less time spent on ladders, lifts and scaffolding, or handling heavy materials;
- Better quality control;
- Better control of material inventory from loss, damage, and the elements;
- Lower risk of on-site material loss;
- Helps address skilled labour shortage as training can be specific to a single operation, and enables on-site work to be completed with less skilled labour, and;
- Solutions can be scaled and rapidly deployed.

1 The anomalous increase in productivity in 2020 is attributed to a decline in economic activities during the pandemic. The contraction in output and employment was particularly large in those sectors that tend to employ workers who are younger and less educated. As these sectors contracted, the average experience and education of workers who continued to work rose, contributing to growth in average worker skills and average labour productivity. [31]

1.6 The nature of Canada's housing stock

As of 2018, Canada's housing stock consisted of 15.8 million units [9]. Approximately 54% of this stock are detached single-family units, 12% are low-rise row and semi-detached dwellings, 2% are categorized as mobile homes, and the remaining 32% are apartments. Of the apartments, a reasonable estimate is that 30% (or 10% of the total stock) are low-rise.

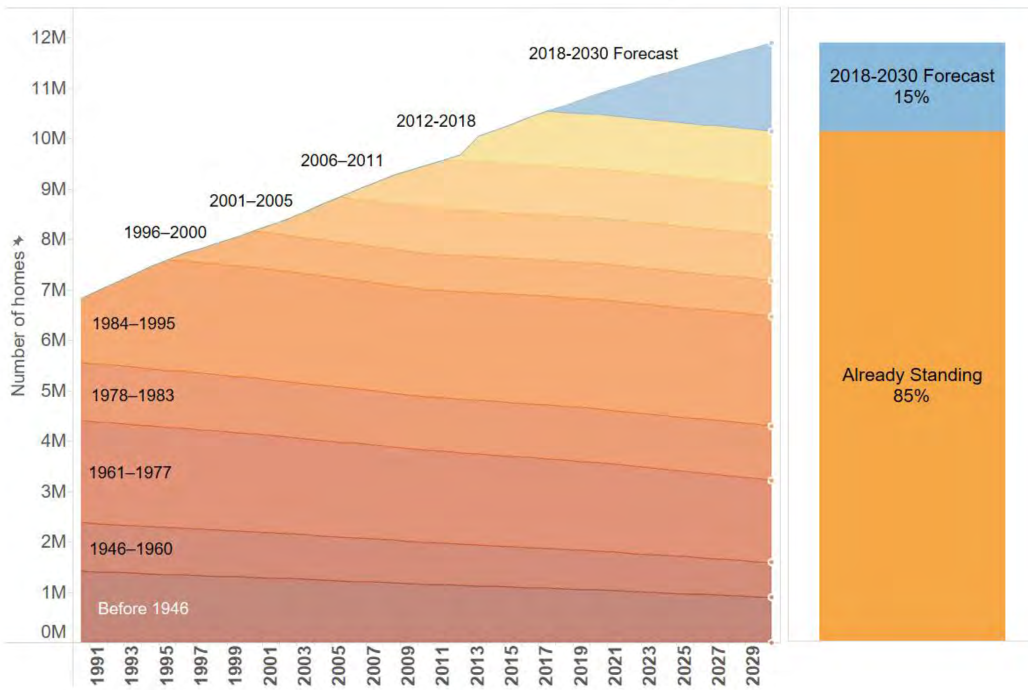


Figure 1-4: Canadian low-rise housing stock by vintage. The vintage bins represent building code cycles.

Thermal resistance and airtightness targets to retrofit existing homes will vary by performance target, climate zone, typology, existing conditions and construction. Notional target R-values are provided in Figure 5-2.

1.7 A burgeoning retrofit economy and market

Countries around the world are preparing for a burgeoning retrofit economy to meet their decarbonization targets. Innovations are needed in policy, construction technology, contracts, and business models to usher in this wave. This document is limited to panelized wall solutions, but others are working to build the retrofit ecosystem and market in Canada.

As discussed earlier, the social housing stock is an excellent candidate for PEER projects and can serve as a platform to establish the panelized approach. Once a market is established in the affordable housing sector and costs are compressed through experience, other potential markets include market-rate rentals, university and college residences, Canadian Forces housing, northern and remote community housing, communities of similarly constructed housing, and privately owned homes.

1.8 The importance and the challenge of tackling building enclosures

The building enclosure (or envelope) is comprised of the foundation walls and slab, the above grade wall assembly, windows and doors (fenestration), and the roof assembly. The enclosure separates the “indoors” from the “outdoors.” To accomplish this, it has to control rain, air, vapour and heat. All four are key to a long-lasting, durable, and resilient high-performance building.

Existing homes are often more tolerant of water control defects. Heat and air moving through a wall for example, may dry moisture that has entered through a flashing defect. Energy retrofits can change this dynamic by reducing heat flow and thus reducing the drying potential. To avoid mould, decay, and other moisture related problems, it is critical that water control details are designed and executed properly to, limit possible moisture sources and paths, while also providing a mechanism for moisture to dry over time.

The next priority is controlling air flow. In addition to the energy penalty, there are also comfort, health and durability implications to excess air leakage, with the potential for drafts, condensation, mould growth and degradation of materials. Air control is accomplished with a continuous air barrier system, which can be very challenging to achieve in an existing building with a piecemeal approach.

Except for window and roofing replacement, the building enclosure tends to be left intact for decades (often 50 years+). Because of its longevity compared to mechanical systems, a building enclosure will typically warrant the higher investment required to improve its performance.

Home heating equipment upgrades have long been considered “low-hanging fruit” in energy retrofits. However, there is a practical limit in how deep a retrofit can be without tackling the enclosure. To achieve significant energy savings, and to improve durability and resilience, the building enclosure needs to be addressed in a comprehensive way.

1.9 The co-benefits

While the objective of a PEER retrofit is to reduce energy use and greenhouse gas emissions, with careful design, planning and execution, such retrofits can also improve occupant health and comfort, and building durability and climate resilience.

Health and comfort

Comfort problems, such as drafts and cold surfaces, may result from insufficient insulation and air leakage. Many occupants experience low winter humidity levels and excessive summer humidity. Health and comfort can be significantly improved with a deep retrofit. By controlling unwanted air leakage and providing fresh air through mechanical ventilation, CO2, and other pollutants such as radon and volatile organic compounds (VOCs) will be reduced. By insulating on the exterior of the framing and sheathing, the surface are raised, and the potential for condensation and mould growth is reduced.

Building durability and climate resilience

Incorporating well designed and executed water management details into building enclosure retrofits will improve the durability and resilience of the building to extreme weather events. As the thermal resistance of assemblies is increased however, their drying potential is typically reduced. It is critical, therefore, to keep these assemblies from getting wet in the first place.

2. THE NATURE OF PANELIZED DEEP RETROFITS IN A CANADIAN CONTEXT

2.1 The European experience with industrialized retrofits

The PEER project was inspired by European innovation such as Energiesprong. Originating in the Netherlands, Energiesprong is an initiative to aggregate demand for retrofits, to set clear standards and energy goals and to industrialize the approach to net-zero retrofits to deliver lower-cost, high-quality, rapid results [1].

Many of the successes of the Dutch approach can be adapted to Canada, with an understanding of how the Canadian context compares.

Table 2-1: The Dutch context compared to Canada

	The Netherlands	Canada
Climate	Moderate, maritime, one zone. HDD: 2,800. Mechanical cooling typically not required.	Cold, humid continental, six zones HDD: 2,700–12,000, with most dwellings below 6,000. Mechanical cooling is common.
Population density	High (488/km^2).	Low (4/km^2).
Building tradition	Structure: Masonry/concrete. Roofing: Slate tile over wood framing. Foundation: Concrete. Typically uninsulated, shallow crawlspace. No basements.	Structure: Light wood frame. Roofing: typically asphalt shingles over wood framing. Foundation: Concrete. Typically, with basements.
Energy costs	High.	Moderate.
Heating system	Hydronic.	Forced-air.
Airtightness	1.5 ACH_{50} [14].	1940: 10 ACH_{50}, 1960: 7.4 ACH_{50}, 1980: 6 ACH_{50}, 2000: 4.3 ACH_{50}, 2019: 2.5 ACH_{50}.
Ventilation	Required, both exhaust-only and balanced systems are common [15].	Required, both exhaust-only and balanced systems are common.
Prevalence of prefabrication	Long history, wide use.	Recent history. Less prevalence but increasing.

2.1.1 Energiesprong technical approach

The Energiesprong retrofits typically include a new panelized, insulated façade made up of unitized panels with new fenestration and a panelized, insulated roof. The new wall panels are installed directly over the existing typical masonry walls. Existing roof tiles are removed before new roof panels are installed. Vents are blocked before crawl spaces are filled with loose expanded polystyrene (EPS) bead insulation.

Panel joint gaps are typically around 12mm, and air barrier continuity is achieved with gaskets. Measured infiltration rates are very low, typically in the range of 0.18-0.26 CFM/ft^2 @ 50 Pa (0.914-1.32 L/s/m^2)[2] ([16]). Ventilation air is supplied with a balanced heat recovery ventilation system.

Wood frame panels and EPS-based structural insulated panels (SIPs) are both employed. Panel fabrication was originally manual and occurred on basic framing tables or on shop floors. However, some suppliers (i.e., RC Panels) have begun to automate the fabrication of retrofit panels.

2.1.2 Energiesprong experience to date

The first completed projects, mostly two storey row houses, to achieve net-zero energy performance are reported to have cost €130,000 (CAN$186K) in 2016. According to a report published by NYERSDA [17], the cost had been reduced by 50% by 2018 (to roughly €65,000). Anecdotally, however, it appears that costs to achieve net-zero may be considerably higher than the figure reported in the NYSERDA report. Additional cost compressions may be possible from standardizing solutions, integrating supply chains, bulk purchasing, and automation.

Monitoring reveals that projects are achieving net-zero performance. Construction duration was noted as a resident complaint, however, the use of prefabricated components likely reduced the construction time considerably from a purely site-built approach. Construction duration is typically one to four weeks. Buildings remain occupied during the renovation and most of the work is completed from the outside.

2.2 The Canadian context: retrofit evolution vs revolution

Energiesprong represents a revolutionary approach to traditional retrofit–characterized by inefficient, site-intensive construction methods and high costs–in favour of a large-scale, industrialized approach to transform the existing housing stock more quickly and economically.

Inherent in the Dutch approach is the idea that creating a large market is a prerequisite for enticing an industry to make the capital investment needed to develop and manufacture a new type of product. Further, there is an underlying assumption that automation is the key to making the product inexpensive enough for the business model to work.

While a piecemeal approach to building retrofit is common to both countries, there are important differences between the Canadian and Dutch contexts as outlined in Table 2. Compared to the Netherlands, Canada is less densely populated, has more climatic zones, code jurisdictions, varied construction practices, more small industry players and larger travel distances. It is

2 While there is not a direct conversion between ACH50 and NLR50 the National Building Code of Canada 2020 (NBC) provides airtightness compliance levels in terms of both ACH50 and NLR50, as well as Normalized Leakage Area NLA10. From the NBC compliance levels for attached units using unguarded airtightness testing, the measured NLR50 range of 0.914–1.32 L/s/m^2 is roughly comparable to 2 to 3 ACH_{50}.

anticipated that transportation costs alone will limit market size in most parts of the country to the point where, at least in the short term, there will be little appetite for making large investments in plants and equipment.

In light of these differences, it is less important to focus on how many companies are willing and able to invest in developing a new product, in favour of how to craft a PEER methodology that accounts for the existing makeup of the Canadian industry and makes best use of the products and services it currently offers - more evolution than revolution.

2.3 Much more than just panels

Although a goal of the PEER project was to eliminate as much of the cost and time associated with traditional approaches, there's no avoiding the fact that a deep retrofit is a major construction project. The wall panels comprise only a part and will likely represent a fraction of total project costs. As part of a deep retrofit, typical projects may also include excavation and work below grade to damp proof, insulate and air seal foundations, reroofing to insulate and air seal above the existing roof deck and the addition of new mechanical systems including ventilation with heat recovery. If fuel switching is part of the program, the cost of removing gas supply and increasing electrical service size can also be a significant cost.

2.4 The team–roles and responsibilities

The successful completion of a deep energy retrofit requires a skilled and experienced team. A PEER project is no different in this regard, except that new roles such as a building capture surveyor, panel fabricator and installer are required. Additionally, given the novelty of the panelized approach in Canada, professional expertise such as that of an engineer or architect may be necessary from a practical perspective or to address concerns of building officials. The following *Table 2-2* outlines the roles and members of a PEER project team.

Table 2-2: Project team roles

Team Member	Role
Owner(s)	Select candidate properties and finance construction
Architect	Develop technical program, code review, permit application and coordinate consultants
Energy Advisor	Conduct energy and carbon analysis
Building Scientist / Envelope Consultant	Conduct building condition assessment and hygrothermal assessment
Structural Engineer	May be required to assess condition of structure and its ability to support the retrofit and to design connections
Building Capture Surveyor	Conduct field survey to acquire measurements and verify
General Contractor	Responsible for all aspects of project delivery. May fabricate panels or subcontract. Likely to use own forces to prepare building to receive panels and is responsible for airtightness.
Panel Fabricator and Installer	Develop shop drawings based on building capture data, fabricate panels, deliver to site and install

2.5 Panel manufacturers vs panel fabricators vs. contractors

For the purposes of this guide, panel manufacturers are considered to be companies that manufacture a base panel, often using a high degree of automation and manufacturing lines. Examples are structural insulated panels (SIP) or wood-frame wall panel manufacturers. For manufacturers, standardization and repetition are keys to success while custom layers are disruptive. Manufactured panels do not typically include membranes, windows, and cladding. Manufacturers are unlikely to invest in new processes unless the market is large and the business model is certain. For these reasons, panel manufacturers are poorly suited for producing finished panels, but may provide a base panel that could be finished by others.

Panel fabricators produce closed panels (with interior or exterior finishes applied in the shop) that are often finished to a higher degree by including elements such as insulation, membranes, windows, strapping and sometimes cladding. This industry is small but is rapidly growing. These companies typically fabricate panels manually for high-end, custom homes and as such, every project is somewhat unique. These companies have a lower threshold for market size and the mindset required for custom work. Panel fabricators are well suited to produce finished retrofit panels.

General contractors or builders are responsible for overall project delivery. Because general contractors are accustomed to unique requirements for every project, they have internal systems that may be standardized even though every project may be unique. General contractors are also well suited to produce finished retrofit panels if they can find and equip an indoor space for this requirement.

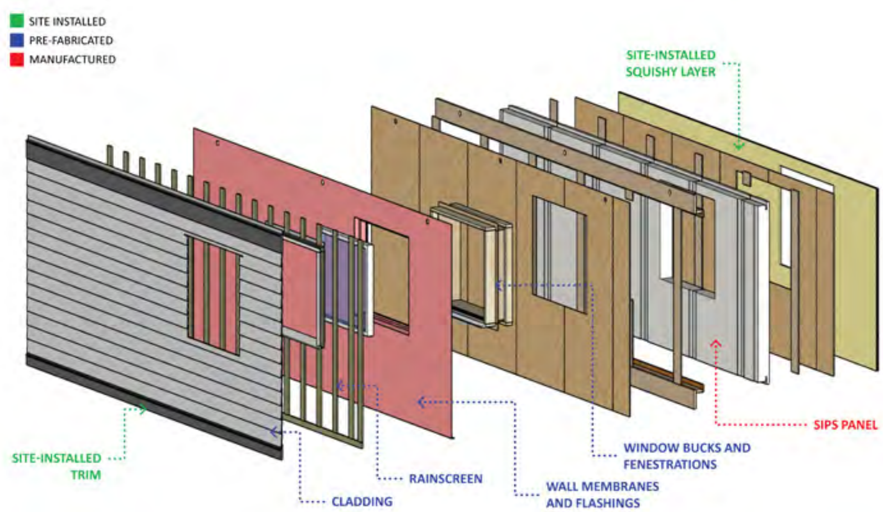


Figure 2-1: Manufactured vs pre-fabricated vs site-installed components

Table 2-3: Suitability of panel fabricators

Category	Product	Mindset	Suitability
Panel Manufacturer	SIP panels or wood-frame component (base panel)	Standardization and repetition are keys to success.	Produces a base panel that could be finished by others Typically not well-suited for producing finished panels but may supply a base panel.
Panel Fabricator	Custom, high performance finished panels	Off-site prefab enables quality control and precision for unique projects.	Best suited to produce finished retrofit panels with insulation, membranes, windows, cladding. Panel fabricator will likely be responsible for installation.
General Contractor	General construction, typically focussed on on-site work	Every project is unique.	Well suited to produce finished retrofit panels if they have suitable space and equipment. In this case, GC responsible for install.

2.6 The value of Integrated Project Delivery

The PEER process workflow can be roughly divided into two parts project definition, and project delivery. Project definition is about defining the problem, which building type, how many units or suites, pre and post retrofit performance, panel design, financing model, etc. Project delivery covers all the steps required to produce and install panels and complete all other site-related tasks.

While the process may appear linear, delivery starts when definition ends—the two are in fact interwoven. To illustrate, we have considered three possible project delivery methods, Competitive Tender (CT), Request for Proposals (RFP), and Integrated Project Delivery (IPD). The intention is to show how the choice of a delivery method can influence how the problem is defined, the solutions that are developed, the cost, and the overall project viability.

2.6.1 Project definition

Step 1: Project definition starts with a Strategic Plan defined by a building owner working with appropriate consultants—most likely an architect familiar with the technical issues; an energy advisor; a financial expert; a building scientist; a municipal planner. Issues to decide include problem definition, financial model, budget, potential funding sources, timeframe, suitability of building stock, tenant demographics, and project delivery method. At this stage relevant policy documents would be identified including the community energy and emissions plan maintained by the municipality and/or strategic energy plan maintained by the housing provider. A tenant communications and engagement plan is also to be developed, as tenant behaviour is a key component of targeted energy savings.

Step 2: A Technical Program is developed: a multi-criteria project selection methodology is followed to identify candidate buildings; current energy performance is determined; post-retrofit objectives are defined. Consultants include an architect, an energy advisor, a panel fabricator, and a contractor. This could be done in the form of a facilitated charrette.

2.6.2 Project delivery

Three basic forms of project delivery are outlined below—Competitive Tender, Request for Proposals and Integrated Project Delivery. Several variations of these are possible.

Table 2-4: Project Delivery Options

Delivery Method	Description	Considerations
Competitive Tender (CT)	Solution decided and tender documents prepared by expert consultants	• Top-down process limits innovation - confined to established solutions known to consultants. • If costing is not done during design, money is spent to prepare tender documents before knowing realistic project costs. • Key industry participants don't get to influence solution, missing opportunities to innovate or optimize. • Process can be slow and iterative - decision whether to proceed cannot be taken until tenders received.
Request for Proposals (RFP)	Solutions developed by various proposal teams	• Project team members are assembled by main proponent on the basis of their relevant expertise. • Collaboration between team members likely to produce a more cohesive solution than CT method. • Greatest potential for innovation (assumes there are several bidders and a variety of possible solutions). • RFP must be performance based—e.g., specifying target energy savings—but must provide reliable frame of reference—i.e., data on existing building construction and current energy performance. • If the RFP frame of reference is flawed, contract disputes can occur. • Beyond performance targets and cost, evaluation criteria may include speed of installation and degree of occupant disruption. • Evaluation of proposals and project monitoring requires appropriate expertise. • High cost to develop a proposal and contract performance risk likely to limit participants to large industry players. • To attract large industry players, individual projects will have to be of a sufficient scale, increasing overall risk if process and technical solutions are untried.

Delivery Method	Description	Considerations
Integrated Project Delivery (IPD)	Solution reflects input from all key stakeholders	• Seen as a natural progression from the collaborative processes in Steps 1 & 2 i.e., a group comprised of people who represent all the key areas of expertise is convened to develop a design solution. • Process lends itself to early phase PEER where there are no established technical solutions or methods of procedure. • Success depends on willingness of all participants to share sensitive cost and profit information. • Costs are known early so a decision whether to proceed can be made sooner than other two methods. • Earlier certainty of go-ahead means that it can be fast-tracked - e.g., activities like building capture can be done during the design stage. • Amount and cost of contract documentation can be reduced because all key team members are party to the decision-making. • Risks can be identified and shared appropriately among team members based on consensus. • Project has a higher likelihood of financial and technical because key players have shared their experience from the outset. • Contract documentation is developed incrementally, reflecting perspectives of all participants, minimizing potential for disputes. • Process lends itself to small projects where up-front costs and risk can be limited due to the cost of bidding being eliminated and all team participants are assured of making their fee.The risk is reduced when the overall value of specific project is small. • Specific solutions are likely to vary by region and the IPD process is more responsive to Canadian regional differences including housing provider funding and management practices, construction norms, building typologies, industry makeup, code requirements, union involvement, etc.

Because panelized retrofits are a new type of construction project where participants likely have little or no prior experience, an Integrated Project Delivery (IPD) method is likely most appropriate. By bringing all the key participants together from the earliest project stage, IPD ensures a much higher level of collaboration; timely information exchange that will result in a better solution at a lower cost while minimizing the risk of costly change orders or litigation.

2.6.3 Energy performance risk

If the contractor rather than the building owner is asked to assume the energy performance risk, the cost of the retrofit will be higher. Energy performance can be predicted by modelling and confirmed by testing, but occupant behaviour and fuel escalation rates cannot be accurately predicted (achieving net-zero energy mitigates the risk of fuel cost escalation). If energy cost is being guaranteed as part of the funding model, an energy cost or energy use base amount must be established and agreed to by all parties. Any amount above the agreed-upon base will be paid by the tenant or the building owner.

3. TECHNICAL CONSIDERATIONS AND “PRE-DESIGN”

3.1 What makes a good PEER project?

Buildings that are simple in shape with repeating units lend themselves to panelized retrofits. If the questions posed below can be answered in the affirmative, then the project is likely a very good candidate for a PEER retrofit.

Mandatory Criteria

- Is there a need for exterior work (windows, doors, cladding)?
- Are energy costs high for a building of this size [high Energy Use Intensity (EUI)]?
- Is the structure sound?
- No building code or zoning issues (setbacks, unprotected openings, heritage designations) that would preclude or complicate an exterior retrofit?

Design and Construction Asset Criteria

- Is the architecture relatively simple? (e.g., few articulations).
- Are there existing drawings?
- Is the building free standing?
- Are the occupants on board?
- Is the entire enclosure accessible? (e.g., no attached garage).
- Are there multiple repeating units?

Site, Location & Transport Asset Criteria

- Is the transportation route free of height restrictions, water crossings, etc.?
- Is there good machine access around the building?
- Is the site free of overhead wires that would interfere with a crane?
- Is there landscaping that cannot be replaced?
- Is there a sufficient staging area?
- Is the site remote? Are there limited local trades available?
- Can the panels be protected from moisture in transit and on site?
- Assuming a Net-Zero target, does the building orientation and site shading allow for roof-mounted solar?

3.2 Setting performance objectives

Achieving significant energy and carbon reductions requires a comprehensive approach that follows “house-as-a-system” principles. A PEER approach could be employed in projects targeting any performance level (net-zero energy, net-zero ready, zero-carbon, passive house). Realistically, there will be one opportunity in an existing building’s lifetime for such a retrofit. Most of the cost relates exterior finishes. The additional insulation and attention to air seal will be relatively inexpensive as a fraction of total project costs. Updating the exterior finishes again in the foreseeable future is very unlikely. This guide, therefore, recommends designing to a net-zero energy or passive house target.

Regardless of the ultimate objective and program followed, there is tremendous value in certification as the voluntary programs listed above require rigor, airtightness testing, and some independent quality assurance controls. Some standards, however, relax in their requirements for retrofits. For example, CHBA’s Net-Zero Renovations Program relaxes requirements for airtightness and some challenging details, such as insulating under the slab. The Passive House Institute’s EnerPHit standard also relaxes airtightness requirements. The PHIUS+ 2021 standard includes the same space conditioning and airtightness targets as new construction but includes larger allowances for existing structural thermal bridging in retrofits.

Table 3-1: Possible performance targets, construction standards and considerations

Target	Considerations	Standards and Programs
Net-Zero Energy or Net-Zero Ready	• Existing orientation, roof pitch and neighbouring buildings, trees may limit potential for sufficient on-site PV. • Contractors and Energy Advisors need to be CHBA pre-qualified. • Minimum airtightness target of 2.0 ACH@50Pa (attached); or 1.5 ACH@50Pa (detached).	CHBA Net-Zero Renovations (Part-9)
Passive House	• Three standards available in Canada for retrofits (PHI, EnerPHit, PHIUS). • Min. EnerPHit airtightness (volumetric): 1.0 ACH@50Pa. • Min. PHI airtightness (volumetric): 0.6ACH@50Pa. • Min. PHIUS+ 2015 airtightness (area based): 0.04 CFM/ft2 of envelope area @50Pa.	Passive House Canada: EnerPHit PHIUS+ 2021
Zero Carbon	• Not intended for Part-9 construction	CaGBC’s Zero Carbon Building Program

3.3 Availability of existing construction drawings

If the building owner does not have existing drawings, these may be available through the municipal building office. These can be immensely valuable at the early design stage to develop schematics and energy models. They can also offer insight into the structural design and assemblies used and can be useful for confirming the placement of elements such as windows in building capture data. However, rarely do permit drawings represent as-built or as-found conditions certainly the dimensions in existing drawings should not be relied upon for the development of detailed panel drawings. Beyond looking for structural and envelope issues with the existing building, the building condition assessment should confirm that assemblies were constructed in accordance with the information in existing drawings. It is important to emphasize that the degree of accuracy required for a panelized retrofit demands a detailed digital survey be conducted to capture all relevant existing dimensions.

3.4 Building morphology

Panel design is more straightforward for simple building forms, and consequently the economics will be better. Architectural elements such as balconies, façade articulation, projecting roofs (that can't be demolished) will all add complexity. It may be possible to simplify the building form as a part of the retrofit (by encapsulating balconies and inset entries, for example). However, these circumstances will likely require one-off custom-engineered details.

There is no minimum number of dwelling units for a panelized retrofit. However, with more repeating units, the process can be made more efficient, and economies of scale exploited. Although each unit should be independently measured (to confirm, for example, that windows and doors are the same size and in the same relative location), repeating forms will expedite panel design, fabrication, and installation.

3.5 Existing enclosure assemblies

The existing assemblies and their condition need to be carefully assessed prior to undertaking a PEER project. If possible, it is helpful to identify existing layers of the wall, the thickness, and measure the moisture content of moisture sensitive materials like wood. Of particular interest are the following elements:

- Are there any existing water management defects that could be potential sources of water ingress (i.e., missing flashing, stains on exterior cladding)?
- Is there evidence of mould growth or rot as a consequence that needs to be addressed prior to retrofitting?
- Is there an existing vapour control layer (i.e., polyethylene, tar-coated kraft paper, multiple coats of oil paint)? The presence of low permeance materials on the conditioned side of the envelope may encourage the use of a panel that facilitates outward drying?
- Will the exterior cladding be left on or removed?
- If an existing reservoir cladding (i.e., brick, stucco, or wood siding) is to remain, how will wetting from rain be managed to ensure that moisture trapped behind the panels will not cause problems?
- Have existing thermal bridges been properly accounted for? Can they be eliminated?

3.6 Site access and suitability

Various equipment, such as an excavator to excavate the foundation and prepare the site, a machine for hoisting panels, and a person-lift for elevated access may be necessary. Machine access on all four sides of the building will likely be necessary. To accommodate this, a minimum clearance of 6m (20ft) will likely be required.

Typically, a panelized retrofit will not require a high-capacity crane. A large, finished panel clad with fibre cement siding might weigh 2.5 Tons (5000 lbs). However, a larger crane may be able to position all wall panels from a single stationary position if the eaves are removed. Situating the crane itself is a key consideration—the size and mobility of the crane needs to fit with the restrictions of the site. With outriggers retracted lifting capacity is reduced, so a confined space can limit the size of panel that can be installed in tight locations. Soft earth may also affect the lifting capacity of the crane. If the crane can only operate from the adjacent street, closures and permissions will need to be arranged.

Panels can also be installed with a boom truck or telescopic forklift, but units with a rotating boom are far preferable to afford fore-aft adjustment.

Overheard wires can complicate hoisting. However, if the retrofit includes electrical upgrades, there may be an opportunity to relocate electrical service underground.

Trees, fences, outbuildings, and neighbouring properties all pose challenges. If possible, the removal of fencing and small outbuildings will make panel installation far simpler.

3.7 Equipment requirements

A skid steer or track loader with a boom attachment is useful for panel handling. Panels should be hoisted from the top to avoid damage. Once windows are installed, panels must be stored and shipped vertically. Custom racking can be fabricated to facilitate panel storage at the fabrication facility, transport, and temporary storage at the project site. A crane, boom truck or rotating telehandler will likely be most suitable for panel handling and installation.

OCH used a small telehandler fitted with a jib to act as a boom lift. This proved useful for manipulating panels in the fabrication shop and in the yard. However, panel installation was slow with the telehandler because there was no ability to move panels fore or aft. This problem would be solved by a rotating telehandler. The machine lacked outriggers, so it was unstable on the muddy or snow-covered site at times.

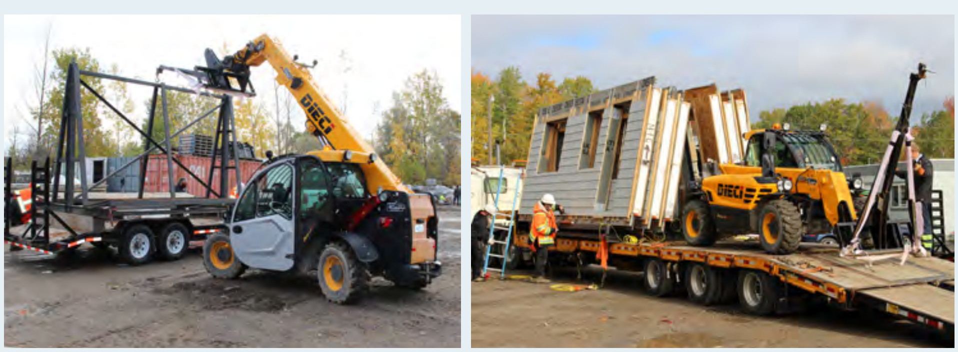


Figure 3-1: (left) telehandler used for hoisting a steel framed storage rack onto a trailer for delivery to the jobsite (right) Telehandler with boom attachment hoisting onto racks on flatbed trailer for transport.

3.8 Building code considerations

3.8.1 Building codes

Canadian building codes are provincially regulated and are primarily intended for the design and construction of new buildings and do not fully cover the scope of building enclosure retrofit work, including PEER projects. Some jurisdictions have requirements related to renovation work, while others do not have specific requirements. As a result, many jurisdictions apply current building codes to significant renovation work and certain types of enclosure retrofits, however the application is inconsistent and the existing conditions of old building enclosures pose challenges, in particular where prescriptive requirements come into play. Cladding replacements, roofing renewals and window replacements for example often fall outside of the building code and this work is often a like-for-like replacement with potential upgrades to thermal performance in terms of insulation or window selection.

Typical challenges that come up during PEER retrofits may result from the pre-existing structural capacity, insulation levels, lack of air, vapour or water control, accessibility requirements, fire protection, and means of egress among other surprises often encountered in old buildings.

All being said, it is prudent for the design of deep retrofits to follow the intent of the current building code, in particular with respect to life safety, accessibility, fire protection and building science principles for the type of work undertaken by a PEER project. The current building code should be followed as closely as possible for any PEER work and will likely be the expectation of registered professionals involved. Deviations from minimum code requirements caused by the existing conditions should be carefully considered during the design stage.

Specific building code items to review when considering the design of a PEER project include:

- The need for an air barrier;
- Condensation control, position of low-permeance materials and outward drying potential;
- Minimum R-values (despite panelized retrofits likely surpassing minimum requirements);
- The need for mechanical ventilation;
- Whether combustible wood framing and foam plastic can be used;
- Other safety considerations including combustion spillage of naturally aspirating equipment.

The Authority Having Jurisdiction (AHJ) *may* require that the current building code be followed for:

- Structure;
- Enclosure (heat,air,moisture);
- Combustibility considerations and fire separation;
- Egress,windows,doors,accessibility and other safety items;
- Relocation of existing gas meters, electrical panels, sprinklers, etc.;
- Setbacks (fire code & zoning) affected by encroaching panels;
- Height restrictions.

For projects in Ontario, Part 11 of the Ontario Building Code (OBC) offers some relaxed compliance alternatives specific to renovations or alterations of existing buildings. If the project is in Ontario, a code review should be performed and applicability of OBC Part 11 should be assessed.

For projects in Quebec, Part 10 of the Quebec Construction Code (QCC) offers some relaxed compliance alternatives specific to renovations or alterations of existing buildings. If the project is in Quebec, a code review should be performed and applicability of QCC Part 10 should be assessed.

Existing building codes are in development nationally, in some provinces and municipalities. The AHJ should always be consulted at the onset of the project for any specific minimum building code requirements the PEER project will need to meet.

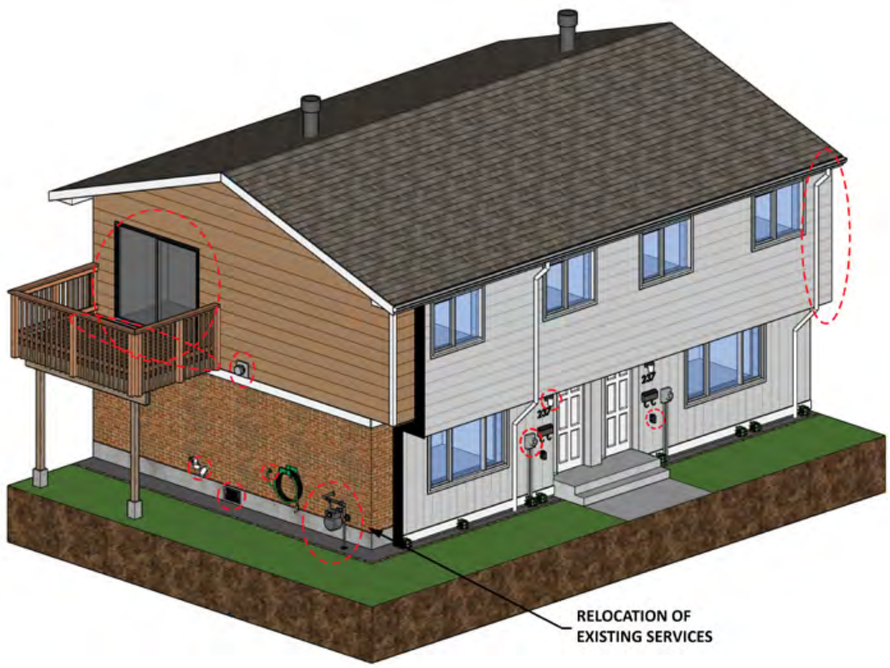


Figure 3-2: A panelized exterior retrofit will result in thicker exterior walls which will require relocation of services, indicated here in red. Brown siding and brick at left shows the existing home profile, while the grey siding to the right is part of new PEER retrofit.

3.8.2 Combustible vs non-combustible construction

The NBC provides spatial separation requirements to reduce the likelihood of fire spread between buildings in Subsections 9.10.14 and 9.10.15. The likelihood of fire spread can be reduced by the following methods:

- Limiting how close a building can be to the property line (limiting distance);
- Limiting the area of openings, such as windows and doors, through which flames and radiation can affect neighboring buildings (unprotected openings);
- Designing exterior wall assemblies to meet a required fire-resistance rating;
- Incorporating sprinklers; and
- Designing interior spaces as fire compartments.

Limiting distance (LD) is a concept used to establish spatial separation and means the distance from an exposing building face to a property line, the centerline of a street, or to an imaginary line between two buildings or fire compartments on the same property, measured at right angles to the exposing building face. PEER projects will reduce the limiting distance, and this may significantly affect the design of the panels, or even the feasibility of using the PEER approach.

Exposing building face (EBF) means that part of the exterior wall of a building which faces one direction and is between ground level and the ceiling of the top storey.

Fire-resistance rating (FRR) means the time in minutes or hours that a material or assembly will withstand the passage of flame and the transmission of heat when exposed to fire. The standard fire exposure condition follows the standard time-temperature curve given in CAN/ULC-S101, “Standard Methods of Fire Endurance Tests of Building Construction and Materials”.

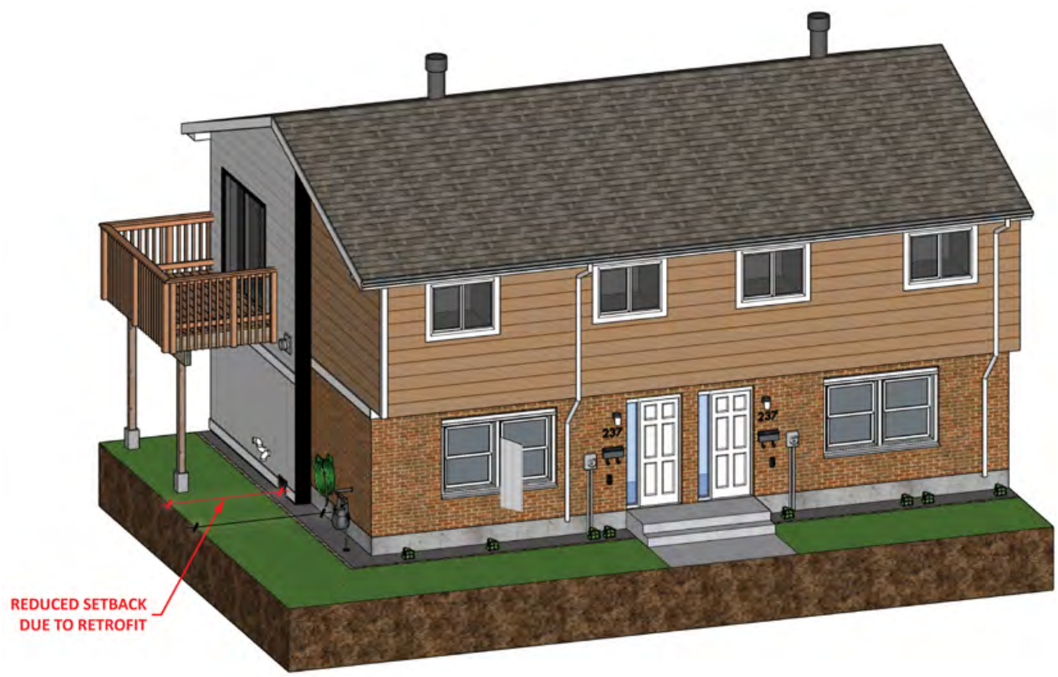


Figure 3-3: A panelized exterior retrofit will result in thicker exterior walls. This may affect minimum setbacks.

Unprotected opening (UPO) (as applied to an exposing building face) means a doorway, window or opening, other than one equipped with a closure having the required fire-protection rating (FPR), or any part of the wall forming part of the exposing building face that has a FRR less than that required for the exposing building face.

Once the limiting distance and the area of an exposing building face are determined, the proportion or percentage (%) of permitted glazed openings (houses) or unprotected openings (other than houses) can be determined and the construction requirements described in Table 6 can serve as a general guideline. It is still necessary to consult the code in force and the Authority Having Jurisdiction (AHJ) for the specific requirements.

Table 3-2 is applicable to Part 9 houses with no dwelling units above another dwelling unit (i.e., single, semi-detached, rowhouses). This Table is also applicable to houses with a secondary dwelling unit.

Note: A secondary dwelling unit is a self-contained dwelling unit within a house, where both dwelling units constitute a single real estate entity (i.e., under a single ownership). The secondary dwelling unit or secondary suite also must meet other prescriptive requirements of the NBC.

Table 3-3 is applicable to Part 9 residential buildings, other than houses.

Table 3-2: Combustibility Requirements for Retrofit Exterior Wall Assemblies under NBC–Part 9

Issue	Limiting Factors	Cladding, Insulation, Construction, Fire Resistance Rating (FRR)
Exterior wall construction based on distance from wall to property line of an adjacent property (LD)	< 600 mm to property line	• Non-combustible cladding. • All types of insulation. • Combustible construction. • 45-minute FRR for Wall Assembly. • No glazed openings permitted.
	600 to < 1200 mm	• Combustible cladding. • All types of insulation. • Combustible construction. • 45-minute FRR for Wall Assembly. • No glazed openings permitted.
	1200 mm and over	• Combustible cladding. • All types of insulation. • Combustible construction. • No FRR for Wall Assembly. • % glazed openings permitted based on wall area and limiting distance.
Protection of Foamed Plastic Insulation	Interior Protection	• 12.7 mm Gypsum Wallboard on interior of wall
	Exterior Protection	• None required

Note: Interior Protection for Foamed Plastic Insulation assumes standard house interior wall finish. Other interior finish may be possible.

Table 3-3: Combustibility Requirements for Retrofit Exterior Wall Assemblies under NBC–Part 9–Other than Houses

Issue	Limiting Factors	Cladding, Insulation, Construction, Fire Resistance Rating (FRR)
Minimum construction requirements for exterior wall construction based on permitted % unprotected openings	Up to 10% UPO	• Non-combustible cladding. • Only non-combustible insulation (no foam). • Non-combustible construction (no wood framing). • 1-hour FRR for Wall Assembly.
	>10 to 25% UPO	• Non-combustible cladding. • All types of insulation. • Combustible construction. • 1-hour FRR for Wall Assembly.
	>25 to 50% UPO	• Non-combustible cladding. • All types of insulation. • Combustible construction. • 45-minute FRR for Wall Assembly.
	>50 to <100% UPO	• Combustible cladding. • All types of insulation. • Combustible construction. • 45-minute FRR for Wall Assembly.
	100% UPO	• Combustible cladding. • All types of insulation. • Combustible construction. • No FRR for Wall Assembly
Protection of Foamed Plastic Insulation	Interior Protection	• 12.7 mm gypsum wallboard on interior of wall.
	Exterior Protection	• None required.

3.8.3 Building permits

Each PEER project will most likely be unique and will require a building permit from the local AHJ. Designers should therefore involve the AHJ in the planning of the retrofit as early as possible and learn the specific requirements for their jurisdiction. Discussions should preferably be held at the conceptual design stages ahead of the development of detailed drawings. This may identify the go/no-go decisions related to zoning setbacks, spatial separation, access, fire protection, structural upgrades, etc.

Exterior panelized retrofit assemblies are not explicitly given as acceptable solutions under Part 9 of the building code; therefore an engineer may be required to review the retrofit assemblies and possibly perform a full structural analysis of the existing building. For buildings falling under Part 4 of the building code, a professional structural engineer should be involved to review the design (in particular lateral load resistance provisions under current vs old codes). Where required by the AHJ or the structural engineer, planning and budgeting for structural design and modification early in the process is critical.

Prefabricated panels may also pose additional challenges for inspections by the AHJ, as many designs will arrive on site with concealed components that are no longer inspectable by the inspector. Specifying fabricators who meet the facility standards and certifications for producing prefabricated panels (e.g., CSA A277 Procedure for certification of prefabricated buildings, modules, and panels) may help address these challenges. Although facility standard requirements like CSA A277 are not particularly common, regulations appear to be heading in that direction. Alternatively, the AHJ could also be invited to review the fabrication of the panels within the factory ahead of delivery to site to become more comfortable with the aspects they would typically review onsite.

In some neighbourhoods, a development permit (i.e., neighbourhood consultation, planning review etc.) may be required if changing the character of the home.

Note that building codes, building permits, and possibly development permits may also impose different requirements where additions to the home will be performed at the same time.

3.9 Design considerations for existing walls

The prefabricated panels are meant to be installed over the existing wall either with the cladding removed or left in place, and the existing windows and their interior trim removed. Prior to discussing the required preparation work ahead of design, it is important to have a general understanding of how the panels may be attached to the building, and how they interface with adjacent/adjoining assemblies.

3.9.1 Structural attachment

Panels are mechanically fastened at the base of the above grade walls, at the following storey(s) floor line(s), and at the roofline. The following section describes this connection for existing light wood, platform-framed buildings. In typical non-structural applications, these attachment locations will need to be designed to support the weight of the panels. For seismic retrofit applications meant to reinforce the structure of the house, a structural engineer will need to be consulted (this is outside the scope of this guide).

As shown in Figure 3-5, the areas of structural attachment need to be exposed and assessed during design development (more details on assessing your existing building are in the following section). These areas include the base of the wall, rim joists and the top plate at the roofline, where the structure will be typically connected back into the existing structure for lateral support and potentially gravity load transfer. Typically, field-installed ledger boards provide the structural attachment between the existing framing and the panels.

Windows and doors will be replaced with the new ones installed in the panel, therefore the structural framing around these elements can and should be exposed and assessed. If there is moisture damage to the surrounding structure, the source of the moisture should be identified, and measures taken to ensure that it is addressed prior to or during the retrofit. This applies to the entire building enclosure, but windows and doors are frequent sources for leaks and replacing them using modern installation practices most often addresses the problem.

If any structural rehabilitation work is required, it is best to identify and plan for this early in the design stage. If this is not possible, contingencies for wood rot repair and fungal remediation should be incorporated in the construction budget.

Panels not intended for seismic retrofits (not meant to laterally reinforce the existing building structure), are typically structurally supported (for gravity or lateral loads) by the existing wall assembly at multiple locations:

- At the base of the wall;
- At the rim joists of each floor;
- At the wall top plates, and possibly the roof framing.

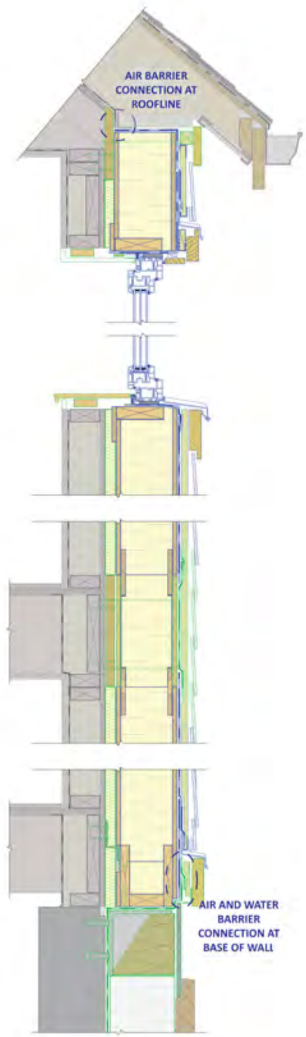


Figure 3-4: Typical structural attachment locations and air barrier connections

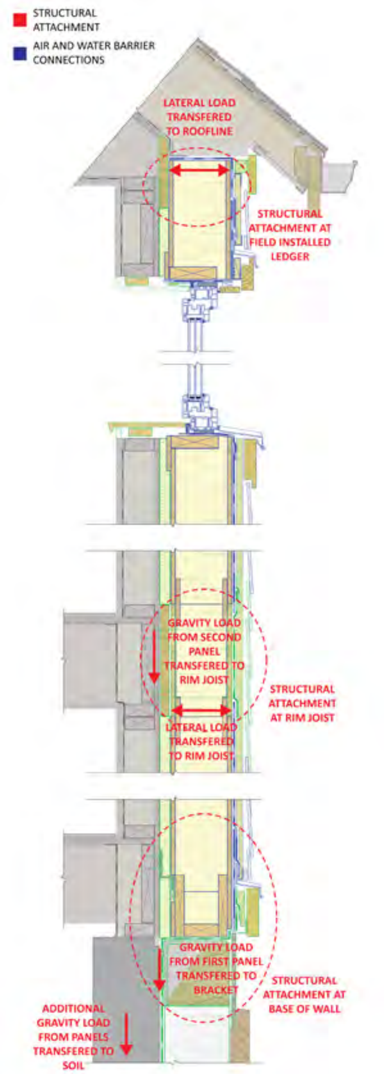


Figure 3-5: Typical structural loading onto existing assembly.

Figure 3-5 illustrates the fundamental load transfer of a typical (non-seismic) panel over an old wall at the previously listed support locations. The retrofit design must consider the following loads on the existing structure:

- Lateral loads caused by wind and seismic activity;
- The weight of the panels (gravity load);
- Any transfer of live or gravity loads from the existing structure;
- Moisture movement due to changes to the existing or new structure after panel installation;
- Thermal expansion and contraction.

Structural engineering will most often be required for specific project conditions. The provided graphics are intended to provide an overview of typical conditions to consider at an early stage of design.

3.9.2 Below grade assemblies

Foundations may be insulated on the interior or exterior. Exterior approaches are preferred for their hygrothermal performance, limited disruption for occupants, and the opportunity they provide to renew aged drainage and waterproofing systems. Specific solutions, however, are outside the scope of this guide.

3.9.3 Roof assemblies

Consideration should be given to upgrading the thermal performance of the roof assemblies through the following approaches:

1. **Maintain existing roof:** Maintain existing roofline, add insulation to attic, install retrofit wall panels directly below existing soffit (this could be challenging for panel installation).

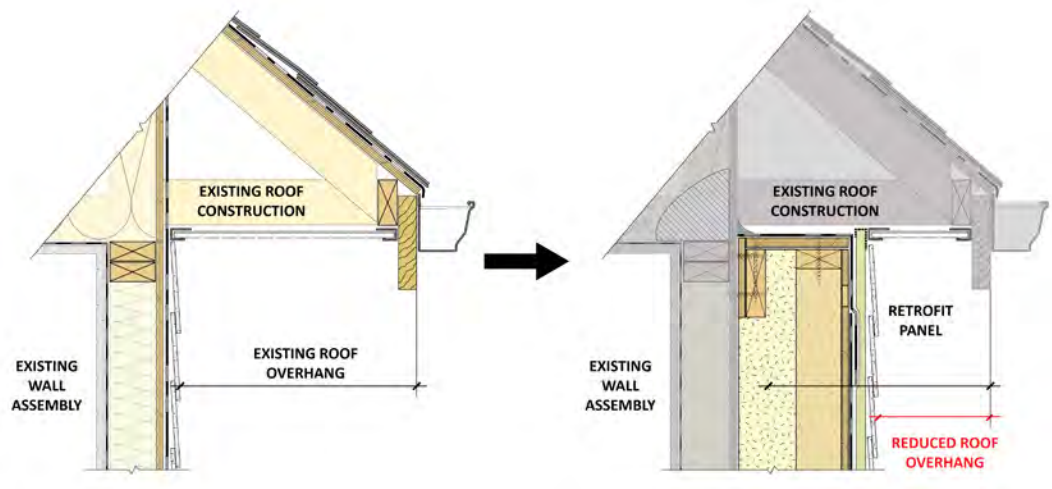


Figure 3-6: Existing overhangs will be reduced following panelized retrofit

Existing roof lines can be maintained when:

- There is sufficient height in the attic to add additional insulation (if required);
- The overhangs are deep enough to accommodate the panel thickness, and continue to meet intended architectural aesthetics, protect the façade, and provide sufficient unobstructed soffit area for ventilated attics;
- Structural connection to the top plate is accessible without the need for modifying the roofline;

2. **Chainsaw retrofit**: Cut off roof rafter/truss tails, install insulated over-roof panels on top of the existing roof deck.

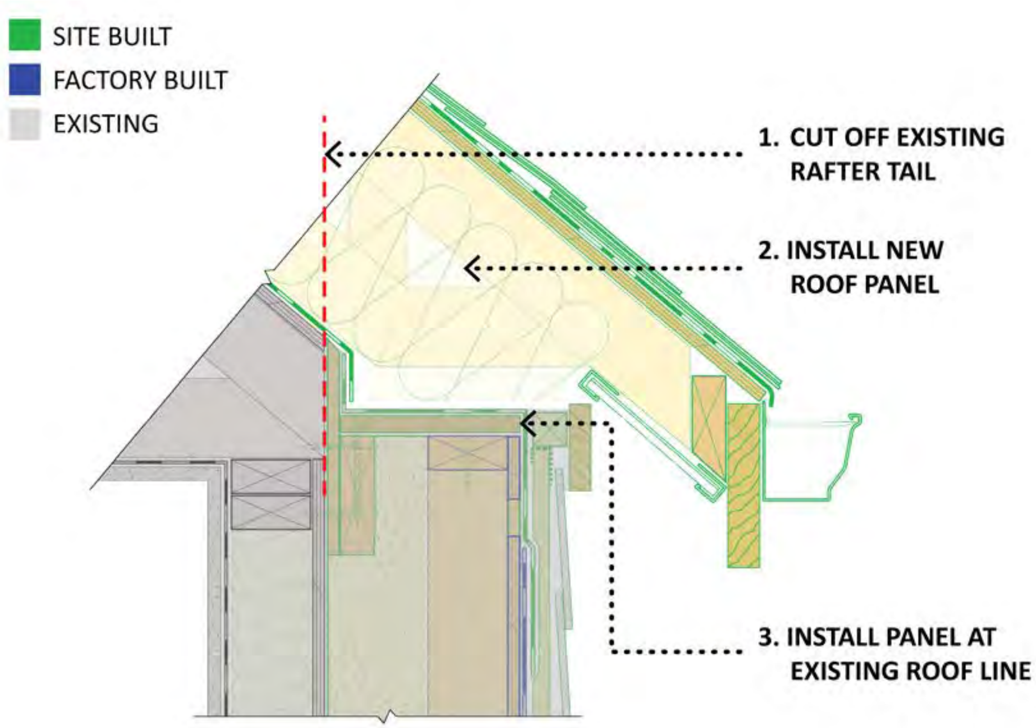


Figure 3-7: "Chainsaw retrofit" to cut eaves flush with wall. This facilitates continuous water, air, and thermal control. Overhangs can be applied or designed into new roof structure.

Further details for roofs are outside the scope of this version of the guide.

3.9.4 Existing insulation, airtightness, and vapour control

Existing insulation: Identify existing locations with low insulation levels (i.e., the roof to wall intersection, attic demising walls). A designer may require this information to assess the post-retrofit hygrothermal risk at these specific locations.

Airtightness and vapour control: A panelized retrofit may reduce a wall system's ability to dry (its vapour diffusion drying potential) and therefore may introduce additional risk of condensation and moisture accumulation to the retrofit assembly in specific circumstances. This risk needs to be thoroughly assessed and accounted for when selecting a panel design, particularly in the following circumstances:

- Air leakage paths exist that cannot or will not be addressed through the retrofit. The building's overall airtightness will affect the relative risk associated with an exterior retrofit. Air leakage typically occurs at common locations such as party walls, dropped ceilings, and penetrations through the building enclosure/air barrier;
- The panelized retrofit will be installed overtop of the existing cladding and the existing cladding can absorb and hold moisture (e.g., brick veneer);
- The existing wall assembly has one or more low permeable materials or vapour barriers (e.g., poly vapour barrier) than can restrict inward drying potential.

In circumstances similar to those outlined above, a panel design with a higher drying potential is preferred. Panel design options and their respective differentiating factors, including drying potential, are discussed in Chapter 6.

3.10 Assessing the building before panel design

3.10.1 Structural assessment

The first step of doing a panelized retrofit may be to hire a professional to perform a structural or geotechnical assessment of the existing foundation to determine if the additional load imposed by the panels can be accommodated. If the existing foundation is not adequate, the required upgrades may add considerable expense to a project.

3.10.2 Energy assessment

An energy advisor (EA) can conduct an evaluation of the existing building’s energy performance and model retrofit scenarios. This will help establish the business case, energy targets, and minimum assembly R-values.

3.10.3 Building / facility condition assessment and capital renewal plans

It is recommended that a building science professional is hired to perform the assessment of the existing building enclosure. This can be a contractor, home inspector, or engineering firm provided they have a thorough understanding of building science principles. If the property owner wishes to self-assess their building, they should be aware that they are accepting the risks associated with any incorrect assessments that are made and may result in additional expenditures down the road.

An assessment of the building needs to be performed for several reasons; these include:

- Informing the panel design and necessary details. It is critical to fully understand the existing assembly. This includes understanding the existing conditions and service lives of the building enclosure components and deciding what is retained versus replaced;
- Based on this assessment, a ***Total Cost of Building Ownership*** forecast can be developed to compare long term costs associated with maintaining the existing enclosure versus a retrofitted enclosure. ***Total Cost of Building Ownership*** analysis includes all quantifiable energy, maintenance and renewal costs related with owning and operating the building for a given period. Given the long lifespan of most enclosure components, it is useful to conduct this analysis over a 30 or even 50-year timeframe. We recommend performing these long-term cost comparisons early in the project to better assess payback periods of the energy retrofit. Additional benefits such as health, comfort and resilience are more difficult to account for, but should be considered;
- Structural considerations which include assessing whether the existing structure needs to be repaired or enhanced in any way;
- Performing an assessment early helps inform retrofit choices and avoid surprises later in construction that could be costly to address. The assessment has the potential to influence the decision of whether to proceed with this type of retrofit.

The following are some tips for performing/managing the assessment:

- Take many photos;
- Mark up what is to be retained or removed based on either the condition or conceptual panel design. Typically, removing the cladding makes for easier installation of the panels and provides an opportunity to inspect the sheathing and framing. Cladding materials that tend to be easier to remove include wood, vinyl, metal, and fiber cement cladding. Cladding materials that may be easier to retain are stone, brick, and stucco;
- Identify gas meters, electrical services, exterior lights, receptacles, hose bibs, and the like that otherwise would be concealed by the new panels;
- The structural load paths and assembly components should also be identified and understood;
- Basements and crawl spaces should be inspected for signs of water intrusion and building settlement;
- Exploratory openings should be made in high-risk locations where deterioration is most likely. For example, openings should be made in wall areas below windows and at foundation bearing to assess the condition of underlying framing, especially where structural attachments might be made. Some examples of typical locations for moisture and insect damage can be found in Figure 3-8 below.

Note that a hazardous materials survey should be performed prior to performing any exploratory opening work. Building owners should be aware of the risks associated with working around hazardous substances such as asbestos, lead paint, mould etc. For more information contact your local workers health and safety authority for local guidelines for dealing with hazardous materials.

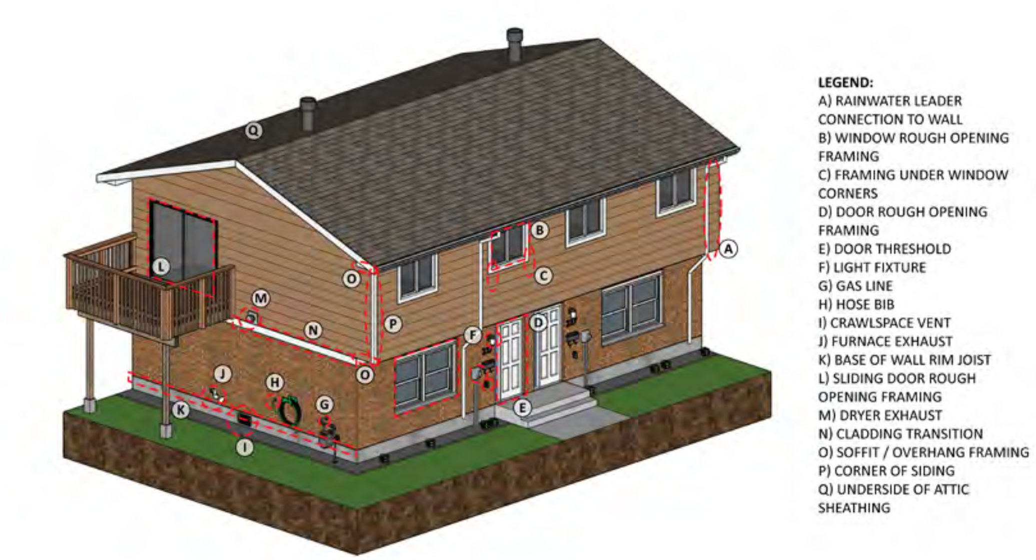


Figure 3-8: Typical locations of moisture/insect damage in building structure.

Once completed, the condition assessment should identify:

- Age and condition of building,
- Status quo cost of ownership (without any alterations),
- Maintenance deficit. What work is needed, when, and at what cost?
- Structural assessment (can the building support a retrofit)?
- Define the useful life of the building.
- Facility condition index: The FCI is the ratio of the renewal cost to the current replacement value.
- For each major building component:
  - Replacement cost.
  - The remaining service life.
  - Comments on condition.
  - Photographs of each component.

More information on performing a building condition assessment can be found in ASTM E2018-15 Standard–Property Condition Assessments [18].

3.11 Assessing potential mechanical upgrades before panel design

3.11.1 Heating, ventilation, and air conditioning (HVAC)

Buildings are systems that involve complex interactions between building assemblies, occupants, and the environment. Changes to one component in a building needs to be considered holistically and the ramifications for other building elements should be understood and planned for. With panelized retrofit projects, it is important to consider the interactions between the building enclosure and the mechanical heating, ventilation, and air conditioning (HVAC) systems. For example, enclosure upgrades should improve the building’s airtightness; therefore mechanical ventilation requirements will need to be reviewed, and a ventilation system potentially added or upgraded. Current building codes should be followed as a guideline for this. Ideally the ventilation system could tie into existing or upgraded forced air HVAC systems. Consider a balanced ventilation system with heat or energy recovery (HRV/ERV) for the best energy performance. The designer will need to work with a mechanical contractor or engineer to design this system.

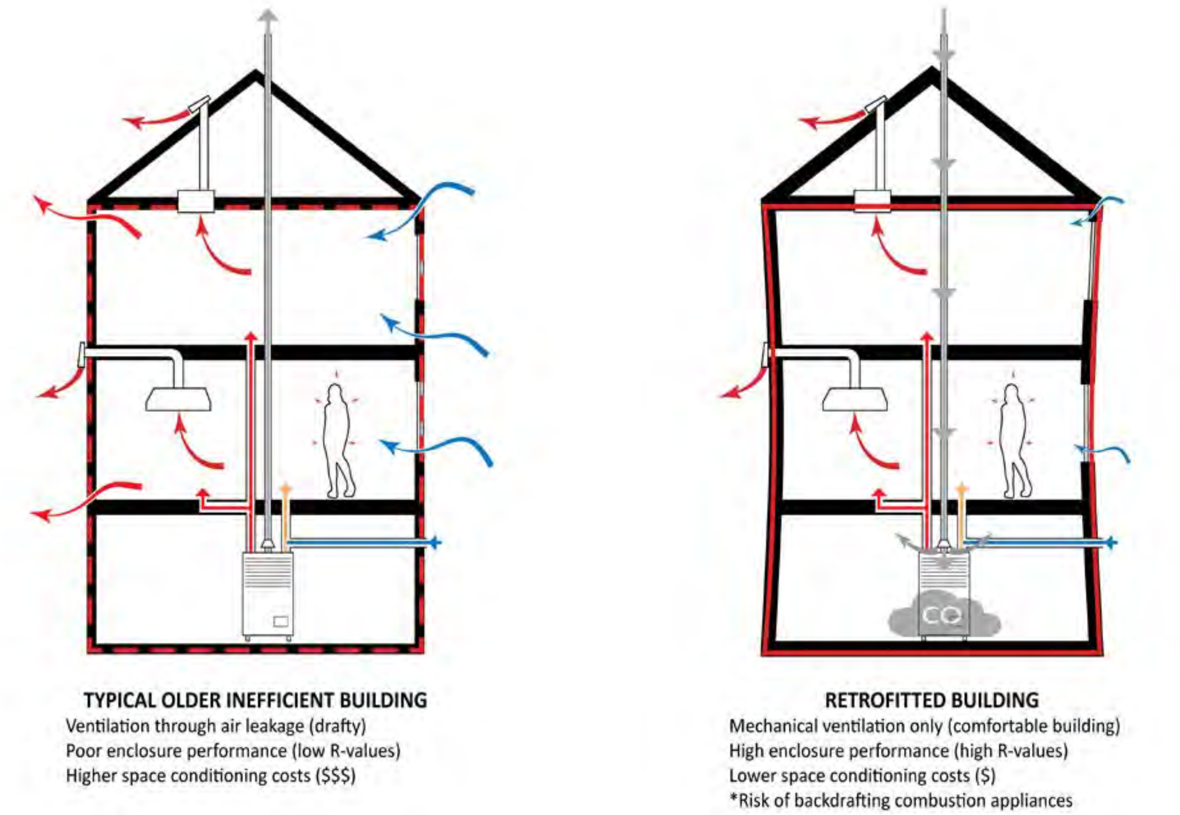


Figure 3-9: When improving airtightness, it is recommended to use a balanced mechanical ventilation system and eliminate naturally aspirated equipment to reduce depressurization and potential for back drafting combustion equipment.

Performing a full upgrade of all mechanicals as part of a deep retrofit (with the assistance of your energy and mechanical consultants) is typically recommended for a few reasons:

- Higher levels of insulation will decrease the HVAC loads. Systems should be right sized for optimal performance, dehumidification and to prevent short cycling and premature equipment failure.
- Naturally aspirated combustion appliances should be replaced as they are less efficient than condensing or electric units and can be unsafe. Back drafting of unsealed appliances and potential carbon monoxide spillage can result following a retrofit without proper make-up air, due to depressurization of the building from any number of sources.
- Fireplaces (wood, gas etc.) should also be reassessed as they may now be oversized for the space and if naturally aspirated, may also require dedicated make-up air following air sealing measures.
- Adding new insulation and sealant materials to air seal a home can reduce indoor air quality if the specified products contain harmful chemicals such as volatile organic compounds (VOCs). These chemicals should be managed appropriately by specifying low VOC materials and/or through encapsulation and proper ventilation.
- Consideration should be given to replacing mechanical equipment in conjunction with the retrofit. Installing HRVs (or ERVs) later as a separate project will be considerably more complicated and expensive. There will be two wall penetrations to make and seal. As the old services are removed it will be necessary to seal and patch new finishes.

When considering mechanical upgrades, first think about where the existing systems are currently installed/mounted. Any equipment installed near to or mounted on the exterior of the home will need to be relocated:

- If installing new HVAC equipment with an outdoor unit (like a heat pump) the retrofit panel and equipment installation sequencing needs to be considered to ensure ease of panel installation. If the outdoor unit is meant to be raised above grade to avoid snow, it may not be feasible to hang the unit from the wall panel.
- Existing dedicated exhaust fan wall ducts all need to be extended, new hoods added, and properly positioned away from windows and air intakes. It is often easier to do this type of work in the field rather than try to locate holes for services of this type in the factory-built panel. The field crew will need to air seal these penetrations.
- A balanced ventilation system (HRV or ERV) is highly recommended. Here again, supply and exhaust penetrations may be better done on-site than in the factory for ease of installation of both the panels involved and the ductwork.
- Where ventilation distribution needs to be added, services like ducting, electrical, and plumbing, could possibly be run through a service cavity between the existing wall and the retrofit. However, thought must be given to whether or how these services can be accessed in the future. Consideration should be made to position such services in relatively accessible locations, such as panel joints where they can be accessed from the exterior.
- Services can also be “roughed-in” to panels in the factory by providing an air-sealed conduit. Some innovative panel fabricators use round, cardboard concrete forms for this purpose.

3.11.2 Services

A panelized retrofit will result in changes to the exterior dimensions of a building; therefore, the design team will need to consider which existing services will be retained and whether they will need to be extended/relocated to allow for the installation of the exterior panels. A few examples of some common considerations:

- Electric meters may need to be relocated.
- If gas service is maintained, meters and lines may need to be relocated.

For the OCH PEER pilot, the gas connections were decommissioned as the retrofit building was fully electrified. New electric meters, disconnects and solar inverters were installed in advance and set on piers that stood far enough away from the building to accommodate the panels. The electric services entered the basements below grade.

Figure 3-10: Ottawa Community Housing electric infrastructure mounted on racks anchored to piers stood-off sufficiently from building to allow panels to be installed behind.

3.12 Building preparation

A guiding principle of the PEER approach is to eliminate unnecessary site labour compared to a conventional retrofit. Traditionally, cladding and exterior trim are removed prior to an exterior retrofit. This affords the opportunity to inspect and repair any damaged sheathing. It also provides insight into whether there have been water control deficiencies and whether further remediation may be needed.

However, demolition is labour intensive and requires disposal of heavy waste. Although diversion, salvage or recycling may be possible, currently most Canadian demolition waste (about 88%) ends up in landfill [19]. Some of this is incinerated for waste-to-energy conversion. Degradable building materials such as wood, if left, will decompose and may emit methane emissions—a potent greenhouse gas. In an ideal circular economy, these materials would be recovered, however at present, to abate emissions and costs, there's a compelling case to leave them in place.

Leaving existing finishes intact will add weight to the overall structure. An assessment of the bearing capacity of the structure (soil, foundation, and walls) will be needed if significant load is to be added. Seismic performance should be assessed as well.

Typical demolition and disposal costs for siding removal and brick removal were estimated at \$9.15 and \$48/m^2, respectively in 2017 (\$0.85/ft^2 and \$4.48/ft^2) [20].

In the 2020 OCH Pilot, the brick veneer and asphalt shingles were left intact. Several brick units were cut out to ensure adequate structural connections of brackets and panels to the existing floor system. Precast concrete window and door sills were cut flush with the brick. The eaves were also cut back to the top plate all the way around the building. The roof deck was also cut at the demising walls to facilitate the installation of new framed demising walls to support the overroof. The canopies and stoops were also removed.

Figure 3-11: Building prep for a PEER retrofit. Canopies, stoops, eaves removed, windows sills cut flush, brick units removed to make structural connections

Porches, canopies, stoops, satellite dishes, mailboxes, wall mounted light fixtures and other such appendages will need to be removed. Coordination with the tenant may be required if the equipment is owned or leased by a tenant.

Coordination with the appropriate utility company is required for removal of the gas meters (and associated piping) as well as the hydro service, cables and conduits.

Exterior stairs and balustrades may need to be removed from the building. Access to the basement of each unit may be required to cut or remove the connections that penetrate the masonry foundation and secure concrete steps to the building.

4. BUILDING OCCUPANTS

Part of what makes a panelized retrofit attractive for social housing providers and rental property owners is the promise that it can be completed with tenants in place. Because much of the work occurs off-site, disruption is significantly reduced. That said, such a project will inevitably impact the tenants. Efforts to reduce this impact, and to maintain clear communication throughout the project will minimize conflict and stress for building occupants and save time-consuming misunderstandings.

4.1 Vacant vs occupied buildings

Projects requiring significant interior work (i.e., asbestos or mould abatement, major structural repair or remodelling) are likely much simpler and safer to perform in a vacant dwelling. However, to retrofit the stock at rates required to meet federal climate targets, many retrofits will need to be completed with occupants in place.

The following additional measures should be considered for occupied buildings:

- Clear daily start and end times for construction work.
- Maintaining accessibility throughout construction (easier to achieve if units have both front and rear access).
- Overhead protection from falling debris for occupants accessing their homes.

Additional information concerning retrofits with occupants in place can be found in *Building Envelope Rehabilitation: Consultant's Guide* [21].

4.2 How will occupants benefit?

In subsidized housing, utilities may or may not be included in the rent. In some cases, subsidy programs may also supplement tenant energy costs. Financial impacts are important to everyone, but particularly to those living in affordable housing who may already be facing a high home energy burden. Cost savings for occupants can be an important incentive for securing buy-in and co-operation for the project.

Other benefits to occupants may include:

- Improved comfort (elimination of drafts, humidity control, less outside noise).
- Improved indoor air quality (when ventilation is provided) and less dust.
- Reduced risk of mould.
- Improved resilience to temperature drops or sharp rises during power outages.
- A renewed exterior to their dwelling contributing to pride of place.

4.3 The importance of clear and consistent communication

Communicating the expected duration of construction and the major stages is critical, as is explaining the overall project objectives and benefits. If occupants understand that the measures will reduce their energy costs and improve comfort and health and improve the appearance of their home, they are far more likely to accommodate short term inconveniences.

A few operations in the PEER process will use equipment unfamiliar to most occupants, and should include some explanation:

- Blower door tests, smoke testing, and infrared thermography.
- Building capture process including laser scanning or photogrammetry surveys, especially those using drones.
- Any monitoring operations should involve a detailed description of what data will be collected and how this will be used and shared.

A sample document that explains the PEER process to occupants is available in Appendix D.

4.4 Dwelling access before, during and after construction

Dwelling interiors may need to be accessed for:

- Building condition assessment.
- Baseline energy assessment and blower door testing.
- Demolition to confirm service locations, or to address structural connections to the building (i.e., pre-cast concrete steps or electrical service masts).
- Electrical and mechanical upgrades.
- Installation of any monitoring equipment.
- Hanging doors if not pre-installed in panels.
- Removing existing windows and doors, installing temporary window covers.
- Trimming out new windows and doors with jamb extensions and casing.

5. PROJECT DESIGN

5.1 Design of panelized retrofit systems

The following flow chart outlines an approach to select the panel type and thickness.

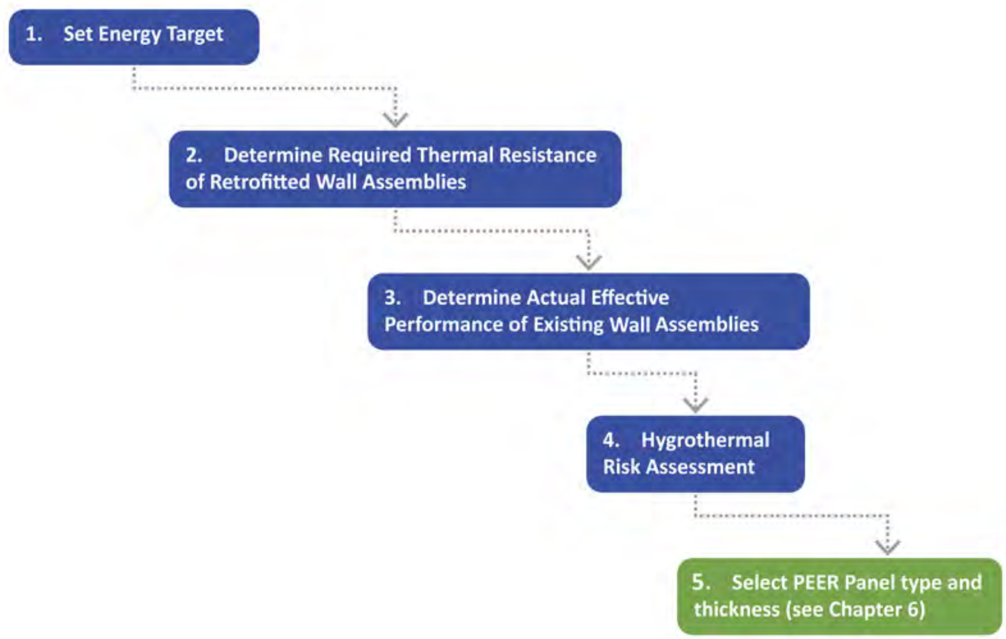


Figure 5-1: Project design and PEER panel selection process

5.2 Energy target

Energy targets will be provided by the project energy consultant. Energy modelling should be performed early enough to set this target prior to panel selection. It is recommended to aim for at least net-zero energy ready performance given the level of intrusion and the cost associated with this work. Adding 200mm (8”) versus 100mm (4”) of exterior insulation, for example, may be a marginal cost that is worthwhile.

The figure below from NAIMA Canada's Guide to Near Net Zero Residential Buildings [22] shows recommended effective R-values to reach net-zero across Canada and can serve as a starting point for early design development, but should be confirmed through energy modelling. These R-value recommendations are for new buildings, with the expectation that all assemblies will comply. In retrofit projects where increasing the insulation of some assemblies (e.g., below slab) may not be feasible, the other R-values may need to be increased accordingly. As a rule of thumb, for retrofit applications, Net-Zero walls will be in the range of RSI 5.3- 8.8 (R-30 to R-50) with a typical median value of around RSI 7.0 (R-40) for Part 9 construction in most climate zones

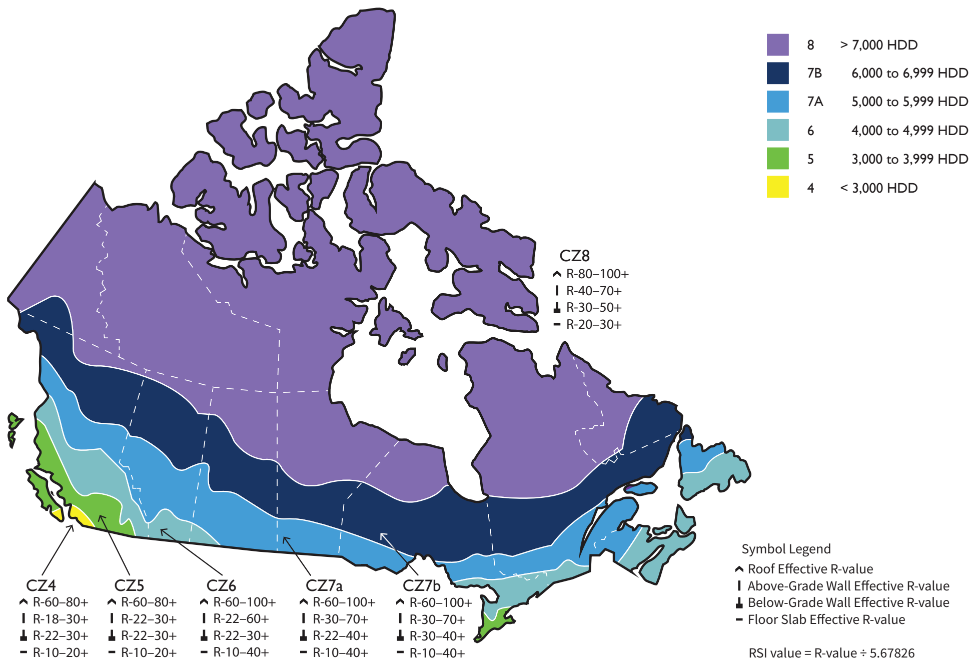


Figure 5-2: NAIMA Canada's Guide to Near Net Zero Residential Buildings recommended R-values to reach Net Zero across Canada.

Note: Insulating and air sealing the building envelope can result in retaining a greater fraction of thermal gains (from appliances, occupants, and solar radiation) that can lead to overheating. The solar heat gain coefficient (SHGC) of windows needs to be carefully considered to balance useful solar gains against the risk of unacceptable overheating. Increased heat gain and decreased heat loss may also be a catalyst to centrally air condition older dwellings; a measure that will help ensure occupant comfort, will prove less costly to operate than window air conditioners and further enhance the appeal of the retrofit to occupants. Assessing overheating risk is beyond the scope of this guide but should be considered. *ASHRAE Standard 55* specifies acceptable thermal conditions [23]. The *Thermal Resilience Design Guide* is another resource that provides design guidance for maintaining comfortable indoor conditions [24].

5.3 Thermal performance

With the energy target established, energy modelling can be used to assess the required post-retrofit thermal performance of each assembly necessary to achieve the target.

In considering wall thermal performance, the wall assembly of a specific project can be broken into two parts: the existing wall assembly, which has a fixed R-value; and the panel assembly, the R-value of which will be specified to meet or exceed the target R-value of the entire assembly.

Wall assemblies on existing older buildings will typically have an effective thermal performance in the range of RSI 0.9 to 2.6 (R-5 to R-15). See Appendix C for typical thermal characteristics of the housing stock.

Installing PEER panels can easily add R-20 to R-40+ to the thermal performance of a building. Clear field thermal resistances for various panels designs and permutations are provided in Appendix B.

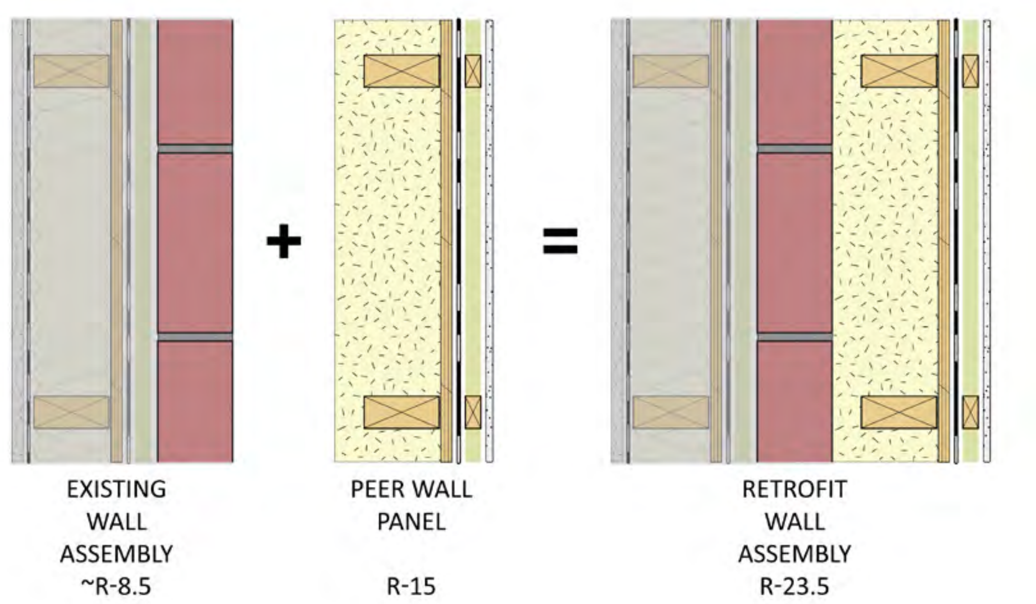


Figure 5-3: *Basic R-value calculation* following retrofit.

5.3.1 Thermal bridging

In determining the thermal performance of both the existing assemblies, and the panels, consideration must be given to the reduction in thermal performance caused by thermal bridging. Areas with reduced insulation, or a more conductive material penetrating the insulation, are called thermal bridges. Thermal bridging can result in excess heat loss and localized condensation issues, and thus are important to minimize.

Panelized retrofits can introduce unique thermal bridges via brackets, beams, and other structural connections. Some details or scenarios a designer will need to pay particular attention to are:

- i) Uninsulated or interior-insulated basements.
- ii) Decks/balconies.
- iii) Attached, uninsulated structures (garages, porches, etc.).
- iv) Top of wall/eave interface.
- v) Beams, brackets, and structural connections for wall panels.

Once all thermal bridges are assessed, the effective thermal performance of the retrofit assemblies can be calculated.

5.3.1.1 Accounting for thermal bridging using linear and point transmittances

The panel clear field thermal resistance is the R-value for the PEER panel with its repetitive uniformly distributed thermal bridges (such as wood-framing members installed in the shop). These values have been calculated using the isothermal planes method [25] for various PEER panel designs, with the results presented in Appendix B.

Linear and point thermal transmittances can be determined through modelling. These account for additional heat flows through specific thermal bridges that may be installed on-site (i.e., steel brackets and wood support beams). Some typical details (panel joints, brackets, and beams) and their associated transmittance coefficients are provided in the following sidebar for the Ottawa Community Housing (OCH) project. Coefficients for other common details and assemblies for highly insulated wood-frame wall assemblies that are site built and may closely represent PEER approaches can also be found in the Building Envelope Thermal Bridging Guide [26] and the accompanying Thermal Envelope Interactive Thermal Bridging Calculation Tools [27].

Linear heat transmittance coefficients (Psi-values (ψ)) represent the added heat flow occurring through linear thermal bridges that are not included in the clear field R-value (such as extra wood-framing at panel joints, window/wall interfaces, roof to wall and wall to grade interfaces, and continuous support beams) and have the units W/m·K

Point heat transmittance coefficients (Chi-value (χ)) represent the added heat flow occurring through point thermal bridges that are not included in the clear field R-value (such as discrete steel brackets or individual fasteners that connect the panel to the backup wall) and have the units W/K.

The overall thermal performance (U-value) of the retrofit wall assembly, can then be calculated as:

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

Where:

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

The effective thermal resistance of the retrofit R-value (R_{eff}) is simply the inverse of the U_T and can be used for the building energy modelling.

Calculating Effective thermal Resistance for the OCH PEER Pilot

Thermal analysis of the OCH PEER pilot design involved calculating the clear field R-value of the retrofitted wall assembly, and modelling specific linear and point thermal bridges, to calculate the overall effective thermal resistance for the retrofitted above grade wall assembly.

Clear Field Thermal Resistance

The clear field R-value of the overall above grade wall assembly was calculated by summing:

+ The exterior air film.
+ The clear field R-value of the PEER SIP Panel.
+ The estimated R-value of the squishy layer fibreglass compressed to 25mm (1").
+ The clear field R-value of the existing wall assembly.
+ The interior air film.

R_{IP} = 45.4

Point and Linear Thermal Transmittances

Thermal bridges were assessed using steady-state heat transfer modelling [28] and thermal bridging tables. The panels sat on a box beam connected to the existing building with steel brackets. Each of the 32 brackets is considered a point thermal bridge, expressed as a Chi (χ) value. The panel joints (horizontal and vertical) and the beam are linear thermal bridges, expressed as Psi (ψ) values. The analysis was carried out to determine the impact of additional heat flows through point (brackets) and linear (panel joints and beam) thermal bridges.

Thermal modelling found that the χ-value for each bracket was 0.046 W/K (0.087 BTU/hr·°F), a relatively small point transmittance. The overall impact from the thermal bridging through the brackets, summarized in Table 5-1, was found to be minimal due to their small count, connection details/materials, and the spacing between them.

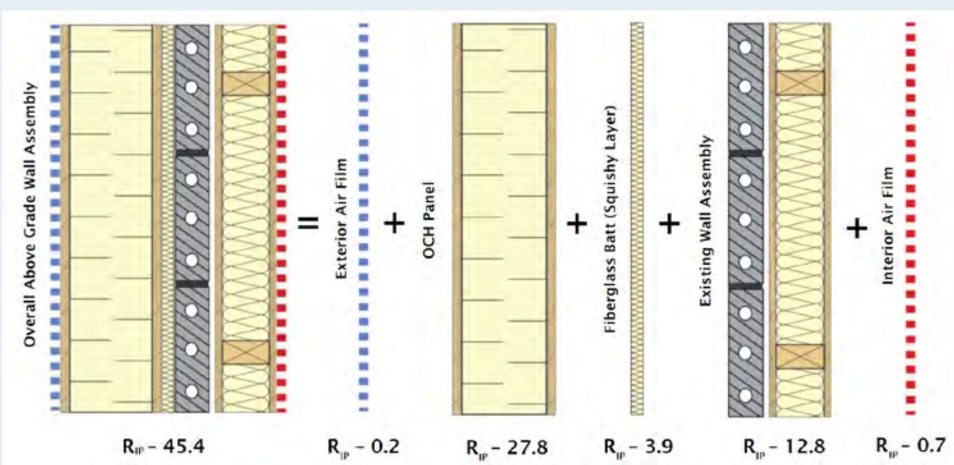
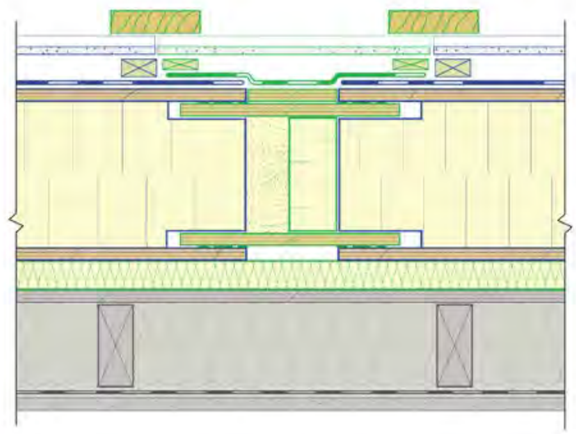


Figure 5-4: The overall thermal resistance of the assembly will be the sum of the panel clear field R-value, R-films, added layers and the existing wall assembly

Vertical panel joints include rebates cut into the EPS to accept oriented strand board (OSB) splines at the interior and exterior face of each panel to bridge the joint, as shown in plan view in Figure 5-8. An expanding foam sealant is installed to occupy void space between the panels and splines.



LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. EPS filler block.
4. Self-expanding foam joint sealant.
5. Front and rear splines glued in place.
6. Site installed self-adhered VP membrane over splines. **(AB/WRB)**
7. Site installed trim over vertical cladding joints.

LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. Site applied cladding and strapping across joint.
4. Self-adhered VP transition membrane sealed over rim panel first floor membrane. Reverse lap at leading edge sealed with high performance tape. **(AB/WRB)**
5. Rim panel fastened and adhered to plywood plumb shim with construction adhesive.
6. Reinforced lifting hole in top of SIP splines.
7. Plywood plumb shim fastened to existing structure at floorline.

Figure 5-5: Vertical panel joint (top), horizontal panel joint (bottom).

The vertical joints were determined to have a Ψ-value of 0.0016 W/m·K (0.0009 BTU/hr·ft·°F) which is considered to be thermal bridge free (<0.01 W/m·K). Therefore, the vertical joints result is no significant reduction to the panel's effective thermal performance.

A rim panel helps align the first and second storey panels, which are fastened through the L-shaped structural members and rim panel into the existing floor framing with structural screws at 1220 mm (4') on-centre. This horizontal panel joint is another linear thermal bridge, although the exterior insulation is not interrupted at these locations. Based on industry available resources [26] [29], the Ψ-value of this connection is estimated to range from 0 W/m·K (thermal bridge free) to 0.04 W/m·K (0.03 BTU/hr·ft·°F). For the analysis, 0.04 W/m·K was assumed. Even with this conservative assumption, the heat flow through this linear bridge is insignificant.

Table 5-1: Thermal performance of the enclosure by assembly.

Clear Field Assembly	Thermal Resistance		Area		% Area	% Heat Flow
	(m³K/W)	(hr ft²·°F/ BTU)	(m²)	(ft²)		
Above grade wall	8.0	45.3	291	3136	41%	12%
Below grade wall	5.7	32.5	136	1465	19%	8%
Linear Thermal Bridges	**Ψ–value**		**Area**		**% Area**	**% Heat Flow**
	(W/m·K)	**(BTU/ hr·ft·°F)**	**(m)**	**(ft)**		
Above to below grade wall transition	0.05	0.03	68	222	-	1%
Window to wall interface	0.03	0.02	69	225	-	1%
Mid wall connection	0.05	0.03	68	222	-	1%
Wall to roof transition	0.00	0.00	68	222	-	0%
Vertical panel joint	0.00	0.00	43	140	-	0%
Point Thermal Bridges	**X-value**		**Quantity**		**% Area**	**% Heat Flow**
	(W/K)	**(BTU/hr °F)**				
Foundation Bracket	0.05	0.09	32		-	0%

5.3.2 Panel thickness

Once the effective thermal performance values are known, the required insulation thickness of the panel can be determined. Thicknesses will depend on the type of panel being used, however, on average, a retrofit panel will provide approximately RSI 0.2 per centimeter (R-3 per inch).

5.4 Hygrothermal considerations:

Increasing the airtightness of an old building and adding vapour-closed layers in an exterior insulated panel will reduce the drying potential and increase the risk of trapping moisture in the wall assembly. Including higher levels of insulation in the panels can assist in reducing the risk of condensation. However, proper water management and adequate vapour permeability is essential for avoiding water ingress issues in the first place, and allowing outward drying in the event of water does enter the assembly.

5.4.1 Bulk liquid water management

Panel joints, interfaces, penetrations, and fenestration provide the most likely locations for water ingress into panels and the backup structure. Designers should ensure that all details for panel joints and penetrations are realistic and can be properly sealed given the construction sequencing and existing conditions of the wall and its interfaces with grade, roof etc. Careful attention to the water resistive barrier and water drainage paths should be made early in design. Should changes to the detailing be required to accommodate existing conditions, ensure that they are designed for, and not left to be figured out on-site during installation. More details on water management specific to different panel types are provided in the following chapter.

5.4.2 Vapour permeability

Vapour permeability is particularly important for projects with porous/hydrophilic claddings that will be retained. For example, a brick building will have the capacity to hold moisture, therefore, vapour permeability in the retrofit panels should be sufficient to allow outward drying of the brick following installation of the panels. Some risk considerations are provided below:

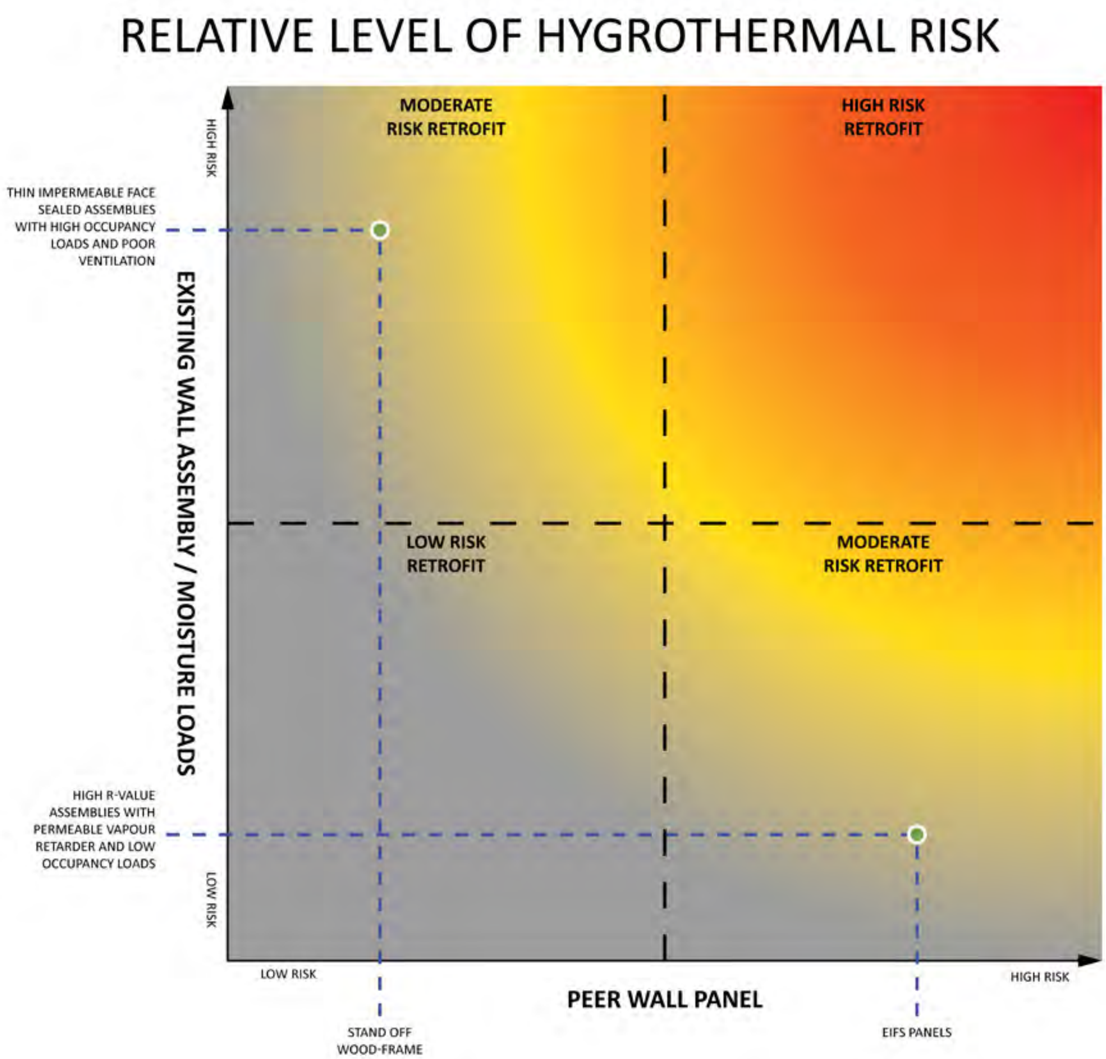


Figure 5-6: Risk considerations for existing assembly and retrofit panels.

5.4.3 Assessing hygrothermal risk of reservoir claddings

Prior to selecting and installing panels over a reservoir cladding (e.g., masonry bricks), it is important to answer the three following questions:

1. What is the expected initial moisture in the existing building envelope, mainly the cladding, when panels will be installed?

2. What is the safe level of initial moisture that will not damage the new panels or be trapped within the existing wall?

3. How long after a rainfall does the building envelope need to dry to reach the safe initial moisture content, or is there a time of year it would be challenging to add retrofit panels?

NRCan and RDH Building Science are developing a hygrothermal modelling protocol to help answer these questions.

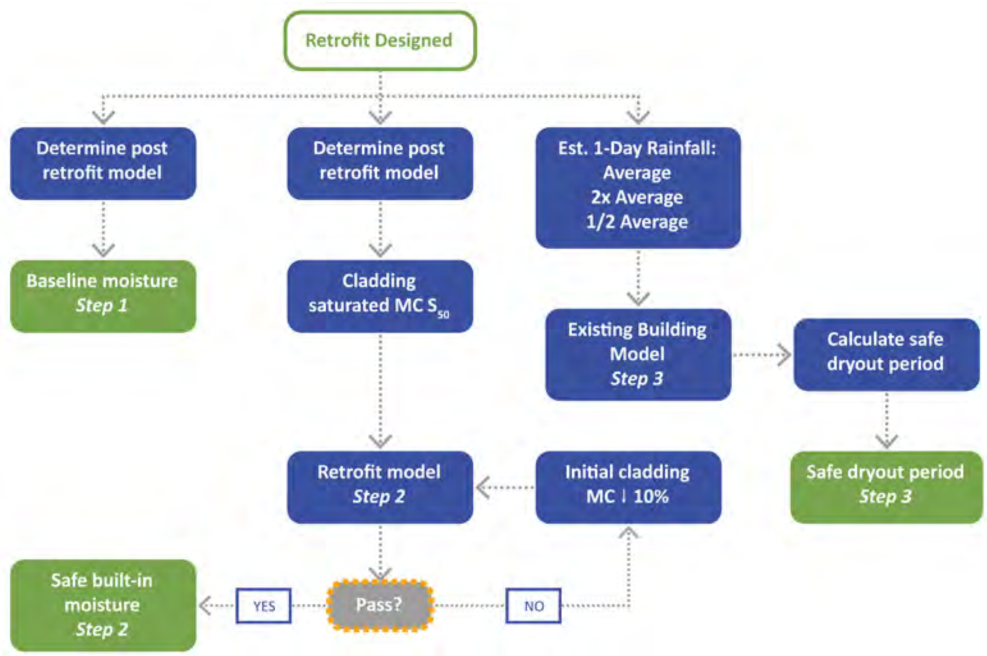


Figure 5-7: Flow diagram for assessing hygrothermal risk of installing panels over reservoir claddings.

The durability criteria include:

1. Total assembly water content: Moisture is not accumulating year over year.

2. Dry out period: Initial moisture of the assembly dries to a relatively stable level within 1-year.

3. Bio-deterioration simulation (Mould Criteria): During the dry-out period, a maximum mould index of 3.0 on every sensitive layer in the assembly, with a desired index of one or less.

4. Wood moisture content (Wood Decay Criteria): After the initial dry-out period, the water content of wood-based layers remains below 20% to prevent decay.

Moisture risk assessment in the OCH project

For the OCH project, the following process was used to assess moisture risk:

Step 1: Develop a hygrothermal model using the brick characteristics.
Three individual bricks were removed and sent to the lab to determine the hygrothermal properties of the brick being used. Then a WUFI model of the existing wall assembly was developed using the actual brick properties as the critical moisture storing variable. The initial moisture in the brick cladding two months prior to the panel installation was simulated using the model.

Step 2: Determine the safe initial moisture content of the brick.
This step involved iteratively changing the initial moisture in the brick, beginning with 50% of the saturated moisture content (S50). If the simulated assembly did not pass the durability criteria, the moisture content of the brick was reduced by 10% and simulation was repeated until the criteria were met. This established the "safe initial moisture content".

Step 3: Determine how long the brick needs to dry to achieve the safe initial moisture content.

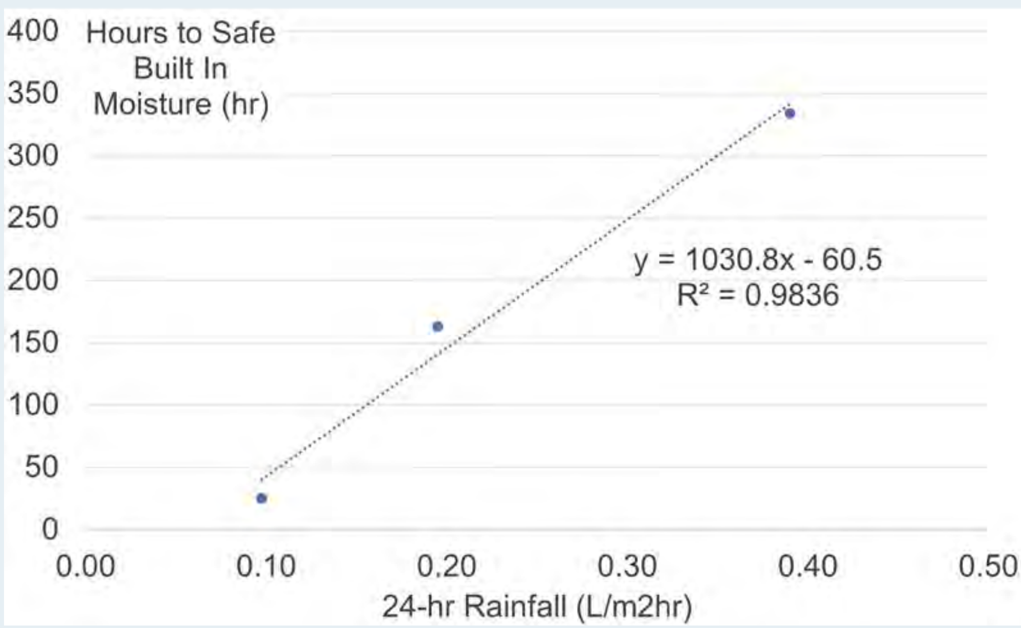


Figure 5-8: Relationship between the time required for brick to dry for a given 24-hour rainfall

From this, we can estimate the number of hours that the cladding should be allowed to dry for a given rainfall intensity and moisture load in the brick.

6. SELECTING A PEER PANEL TYPE

Once the thermal performance target is set and thermal properties of the existing building have been considered, a panelized system can be selected. This section will help define which panel type is best suited for a given project based on their differentiating factors. In general, all panelized systems presented below have the following in common:

- **General installation:** All panelized systems are designed to be prefabricated off-site and reduce the amount of required site work. Nearly all panels, except for the Exterior Insulated Finish System (EIFS) panels, are also designed to be shipped with the windows pre-installed. However, the windows cannot be pre-installed in the EIFS panels due to the weight of windows and lack of structural rigidity of the panels.
- **Attachment:** All panelized systems are above-grade wall panels that are attached to the exterior walls of existing buildings. With the exception of the EIFS panels, all panels are attached at the base of the wall using a series of intermittent foundation brackets, or insulated box beams/rim panels, or both. Lifting straps double as attachment points at the top of panels to connect to pre-installed plywood shims with long screws (see construction details in Appendix A). The current lightweight EIFS panels are attached by hanging them from the existing wall using a metal cleat system.
- **Air barrier location:** All air barrier systems on the panels, apart from the I-joist and EIFS panels, are located on the exterior side of the panel. This allows easy access for sealing air barrier joints following installation of the panels. Panels are sealed to each other at their joints using self-adhered membranes and tapes, or caulking.
- **R value ranges:** Typically, retrofit panels will be in the range of approximately 150-300 mm (6-12") deep. R-value ranges are RSI 3.6-8.5 (R-21 to R-49). These R-values will then be degraded by structural attachments and other thermal bridges.

The following subsections provide an overview of each panelized system and their differentiating factors. These factors are:

- **Outward drying potential:** This is characterized by how easily water vapour can diffuse through and out of a system. This is particularly important for old leaky buildings where large amounts of moisture move from the interior to the exterior through the exterior walls and for buildings with absorptive claddings that will be overclad with the panelized retrofit (e.g., brick veneer).
- **Thermal resistivity:** The thickness of a panel is directly proportional to its thermal resistance. The thermal efficiency of a panel translates into how thick the panel needs to be to meet thermal performance requirements. Put another way, a panel with a higher thermal resistivity (R-Value per unit thickness) will result in a thinner panel profile, an important consideration in higher density settings where space is limited.
- **Embodied carbon:** This represents the “cradle-to-gate” GHG emissions associated with manufacturing the required building materials within a panelized system.
- **Local availability:** This represents how easily and economically all materials within the panelized system can be sourced.
- **Pre-fabrication constructability:** This notes whether the prefabrication of this panelized system requires specialized tools/equipment and personnel.

- **On-site completion:** This notes any special considerations, tools, equipment or limitations for field preparation, installation, and quality-control.
- **Cost:** The material and labour costs associated with all materials and prefabrication of the panels as well as their design and installation.

6.1 Structural insulated panels

6.1.1 Overview

Structural insulated panels (SIP) are comprised of a rigid foam insulation core with structural skins adhered to both sides. A brief description of the panel is provided below, with more details in Appendix A.

6.1.2 Layer-by-layer assemblies

- Exterior
  - Cladding.
  - Treated wood strapping + air cavity.
  - Self-adhered vapour permeable membrane (air barrier and water resistive barrier).
  - SIP: Exterior OSB sheathing, EPS insulation, inner OSB sheathing, layers glued together to form composite base panel.
  - Compressible mineral fibre gap fill insulation.
  - Existing assembly.
- Interior

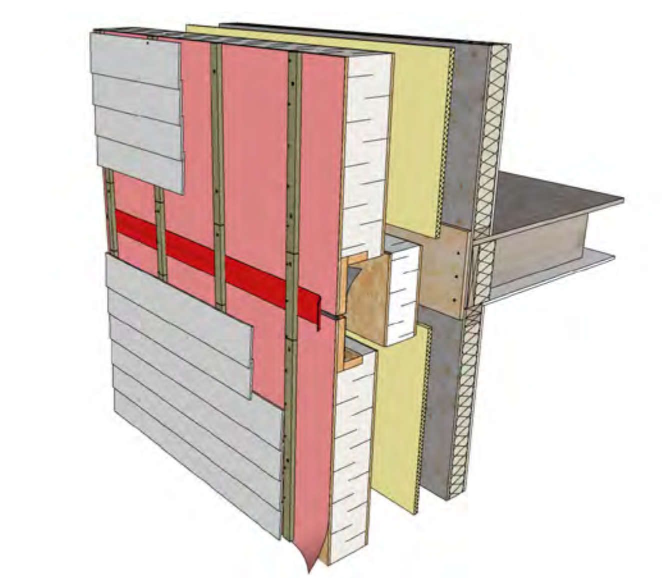


Figure 6-1: PEER Structural Insulated Panel (SIP)

6.1.3 Differentiating factors

Drying potential: SIPs have a relatively low outward drying potential due to the thicknesses of EPS insulation that would be typically used, the two structural skins and the resulting low vapour permeability.

Thermal efficiency: Very little thermal bridging through the SIP panel and the relatively high thermal resistivity of EPS insulation allows this panel to meet thermal resistance requirements with a thinner profile compared to other options. Note that graphite-infused EPS (often referred to as GPS) is available from most SIP manufacturers. GPS has a roughly 20% higher R-value per unit thickness and costs about 20% more. The thinner profile may justify the increased cost.

Embodied carbon: The use of EPS insulation results in moderate levels of embodied carbon (EPS is less carbon intensive than other foam materials). This does not take into account the cladding material that is used, which may vary greatly in regard to its embodied carbon.

Local availability: SIP panels are only manufactured by a few companies in Canada and often need to be transported long distances.

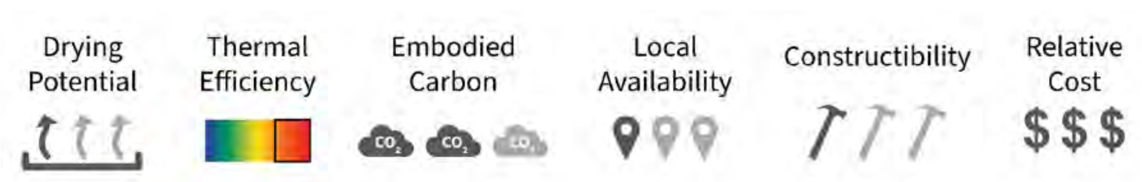
Prefab constructability: SIP panels are manufactured products and require special tools, training, and experienced trades. A manufacturer is most likely to produce a “base panel” that can be easily modified (membranes, strapping and cladding, windows installed) by a fabricator. Because the strapping is only attached to the skin and not framing members, there may be limitations for cladding options.

Panel Size: SIPs are usually manufactured in large billets of 8' x 24' (2.4m x 7.3m) and then cut into smaller sizes. Overall panel thickness is typically limited to a maximum of 12" (305mm) but any increment less than that is normally possible. Standard skin thickness is 7/16" (11mm) although thicker skins (e.g., 19/32"–15mm) which provide increased cladding fastener pullout resistance, may be available from some manufacturers.

On-site completion: Splines can be inserted on-site to strengthen panel-to-panel connections and to provide a nailing base for field-applied cladding/trim.

Cost: Prefabrication and shipping costs may vary depending on location. SIP panels include two layers of structural sheathing, increasing material cost.

Approvals: Not all SIP manufacturers have the building product certification that some municipal building departments require. It can be helpful to point out that SIPs used in a retrofit application unlike in a conventional SIP build do not transfer a gravity load other than their own weight. The panels will however be subject to lateral loads (wind and possibly seismic) so engineering analysis and sign-off may be required. It is prudent to check with the local AHJ early in the design phase about their willingness to approve a SIP-based permit application before committing to a SIP solution.



6.2 Nailbase (Half SIP)

6.2.1 Overview

The nailbase (half SIP) is similar to the full SIP panel but without the interior layer of OSB sheathing. A brief description of the panel is provided below, for more details see Appendix A.

6.2.2 Layer-by-layer assemblies

- Exterior
  - Cladding.
  - Treated wood strapping + air cavity.
  - Self-adhered vapour permeable membrane (air barrier and water resistive barrier).
  - Nailbase panel: Exterior OSB Sheathing, EPS insulation, layers glued together. Continuous structural "L" to stiffen panel.
  - Compressible mineral fibre insulation.
  - Existing assembly.
- Interior

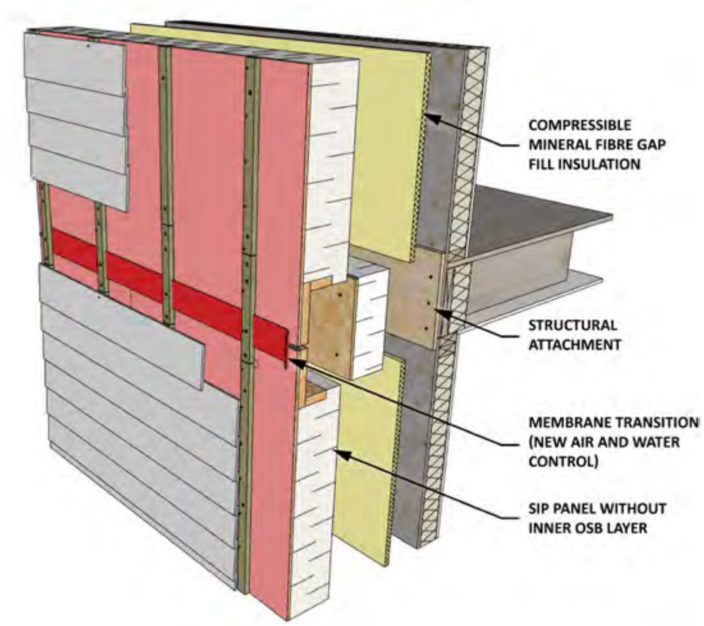


Figure 6-2: Nailbase panel (Half SIP)

6.2.3 Design considerations

Drying potential: Like a conventional SIP, this insulated panel has a relatively low drying potential due to the thick EPS insulation. However, there may be less risk of mould growth due to the absence of the inner OSB layer found in the full SIP design.

Thermal efficiency: Very little thermal bridging through the Nailbase panel and the relatively high thermal resistivity of EPS insulation allows this panel to meet thermal resistance requirements with a thinner panel compared to other options. Note that Graphite-infused EPS (often referred to as GPS) is available from most SIP/Nailbase manufacturers. GPS has a roughly 20% higher R-value per unit thickness and costs about 20% more, but the thinner profile may justify the increased cost.

Embodied carbon: The use of EPS insulation results in moderate levels of embodied carbon. This does not take into account the cladding material that is used, which may vary greatly in regard to its embodied carbon.

Local availability: SIP/Nailbase panels are only manufactured by a few companies in Canada and often need to be transported long distances.

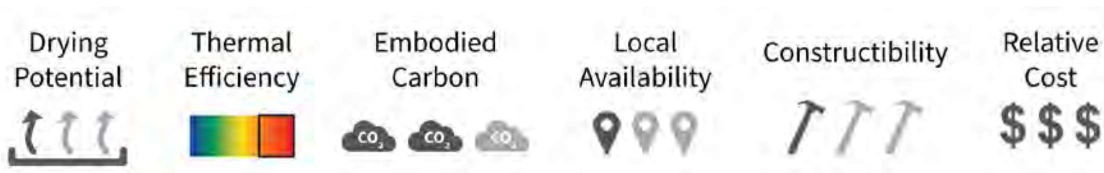
Prefab constructability: Nailbase panels are manufactured products and require special tools, training, and experienced trades. A manufacturer is most likely to produce a "base panel" that can be easily modified (membranes, strapping and cladding added, windows installed, etc. by a fabricator. Because the strapping is only attached to the skin and not framing members, there may be limitations for cladding options. Note that Nailbase panels are more likely than SIPs to warp because the structural skin is on one side only and OSB and EPS expand and contract at different rates. Introducing wood framing "stiffeners" at vertical and horizontal panel joints can help to mitigate warping.

On-site completion: Splines can be inserted on-site to strengthen panel-to-panel connections and to provide a nailing base for field-applied cladding/trim.

Panel Size: Nailbase panels, like SIPs, are usually manufactured in large billets of 8' x 24' (2.4m x 7.3m) and then cut into smaller sizes. Note that Nailbase panels are "flimsier" than SIPs because of the absence of the second layer of OSB. This limits the size of panel that is practical to handle in the plant and on site; most manufacturers will not make a Nailbase panel larger than 8' x 12' (2.4m x 3.6m). Overall panel thickness is typically limited to a maximum of 12" (305mm) but any increment less than that is normally possible. Standard skin thickness is 7/16" (11mm) although a thicker skin (e.g., 19/32"–15mm) which provide increased cladding fastener pullout resistance may be available from some manufacturers.

Cost: Prefabrication and shipping costs may vary depending on location.

Approvals: Not all SIP/Nailbase manufacturers have the building product certification that some municipal building departments require. Unlike a conventional SIP, a Nailbase panel may encounter less approval resistance because it is less likely to be viewed as a "structural" component. The panels will however be subject to lateral loads (wind and possibly seismic) so engineering analysis and sign-off may be required. It is prudent to check with the local Authority Having Jurisdiction early in the design phase about their willingness to approve a Nailbase design permit application before committing to a Nailbase solution.



6.3 Standoff wood-frame panel

6.3.1 Overview

The standoff wood frame panel is a 2x4 framed wall panel with OSB sheathing fastened to the exterior of the frame and site blown-in cellulose insulation. A brief description of the panel is provided below, for more details please see Appendix A.

6.3.2 Layer-by-layer assemblies

- Exterior
  - Cladding.
  - Treated wood strapping + air cavity.
  - Mechanically fastened or self-adhered vapour permeable membrane (air barrier and water resistive barrier).
  - Wall sheathing.
  - 2x4 framing with site installed blown-in insulation.
  - Existing assembly (not shown).
- Interior

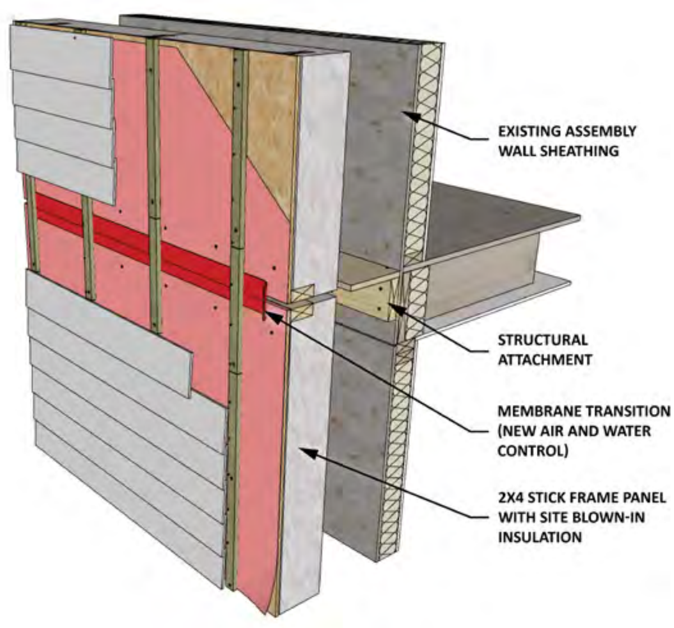


Figure 6-3: Stand-off Wood Frame Panel

6.3.3 Differentiating factors

Drying potential: A 2x4 framed wall with blown-in insulation will provide better outward drying potential when compared to the other panels with rigid foam insulation.

Thermal resistivity: Minor thermal bridging through the 2x4 stud framed walls as well as the relatively lower thermal resistivity of the blown-in insulation may require slightly thicker panels to meet thermal requirements.

Embodied carbon: The main materials used for these panels are wood and blown-in cellulose insulation, which makes this panel a good option for reducing embodied carbon. This does not take into account the cladding material that is used, which may vary greatly in regard to its embodied carbon.

Local availability: These panels are made of materials that are available nationwide. A manufacturer is most likely to produce a “base panel” that can be easily modified (membranes, strapping and cladding added, windows installed, etc.) by a fabricator.

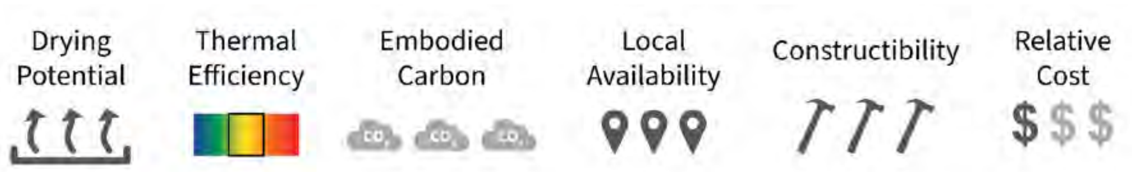
Prefab constructability: The methods used to construct the panels are a simple variation on standard residential building practice, requiring minimal special tools, training, and trades. Since it can be fastened to solid sawn framing members, there is no limitation on cladding options. Insulation access holes can be pre-cut in the sheathing, but it may not be possible to pre-install some trim/cladding (i.e., under windows).

On-site completion: Framing cavities and the stand-off cavity are insulated on-site with blown-insulation (i.e., cellulose). To avoid settling, it is necessary to install such insulation at a minimum density. For cellulose this is typically a minimum of 50 kg/m3 (3.5 lb/ft3). This is more labour intensive than other pre-insulated panel types and requires specialized equipment and installer experience. Care is also required to air seal insulation ports in the field. Some cladding/trim will likely need to be installed on-site to cover the access holes required for blowing in insulation on-site.

Panel Size: The size of Stand-off Wood-Frame Panels is limited by what is practical to handle in the shop, or by size constraints imposed by automated framing equipment and by the length of plate and stud material. Sawn lumber longer than 16' (4.9m) is often difficult to obtain so this can be a limiting factor. Note that Laminated Strand Lumber (LSL) or Laminated Veneer Lumber (LVL) can be substituted for sawn lumber for more dimensional stability and for longer lengths (for two-storey high panels for example), but at a price premium. Both plywood and OSB structural sheathing of any desired thickness can be used.

Cost: The Stand-off Wood Framed Panels use commodity framing and sheathing. Traditionally these have been very cost-effective, but these materials have been subject to large price volatility over the COVID-19 pandemic. The cost for these panels will vary based on the cladding material used.

Approvals: Light wood-frame is the standard construction technology for Part 9 residential buildings in Canada, although the way it is employed in a PEER style retrofit will likely be unfamiliar to most approval authorities. It is also very likely that a structural engineering review and sign-off will be required—something that is not typically required for light wood platform framing. As with the other panel types, it is wise to begin discussions with the local building department at an early stage in the design process to avoid lengthy approval delays at later stages.



6.4 I-Joist panel

6.4.1 Overview

The I-joist panel is a framed wall panel using I-joists as the framing, OSB sheathing fastened to the exterior of the frame and fibrous insulation in the cavities (batt or blown). A brief description of the panel is provided below, for more details please see Appendix A.

6.4.2 Layer-by-layer assemblies

- Exterior
  - Cladding.
  - Treated wood strapping + air cavity.
  - Self-adhered vapour permeable membrane (air barrier and water resistive barrier).
  - Wall sheathing.
  - I-joist framing with fibrous cavity insulation (batt or blown).
  - Insulation retention mesh.
  - Compressed batt or blown-in fibrous insulation.
  - Existing assembly.
- Interior

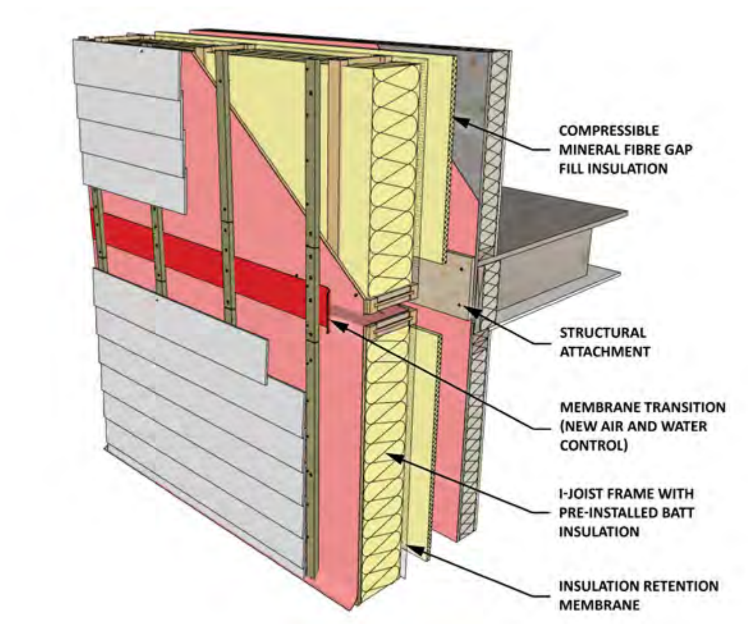


Figure 6-4: I-Joist Panel

6.4.3 Differentiating factors

Drying potential: A framed wall with fibrous cavity insulation will provide better drying potential when compared to other panel types with rigid foam insulations.

Thermal resistivity: Minor thermal bridging through the I-joist web that span the depth of the panels, and the relatively lower thermal resistivity of the fibrous insulation will require slightly thicker panels to meet thermal requirements.

Embodied carbon: The main materials used for the I-joist panel are wood and fibrous insulation. Based on the most commonly available fibrous batt insulation options, these panels may have a moderate carbon footprint. Low-carbon fibrous insulation materials such as hemp or cellulose may be used. This does not take into account the cladding material that is used, which may vary greatly in regard to its embodied carbon.

Local availability: The I-joist panel is mostly made of materials that are widely available, however, there may be lead-time issues depending on location. Unlike conventional wood-frame panels that automated framing equipment is designed to build, I-joist panels will likely be built by hand on large framing tables. In this case, the concept of buying a “base panel” from a manufacturer and having a fabricator install additional layers and components is unlikely. It is more likely that the fabricator will build the entire panel. By taking the manufacturer out of the equation, the I-joist panel can be readily made locally anywhere in Canada.

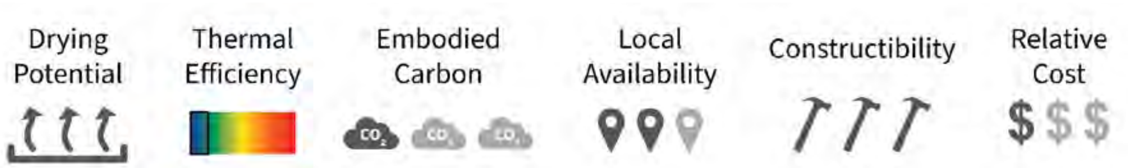
Prefab constructability: The method used to construct the panels is a variation on standard wood-frame construction practice, and as such requires minimal special tools, training, and trades. Since it can be fastened to solid sawn framing members, there is no limitation on cladding options. The use of prefabricated I-joists will expedite fabrication compared to a custom-built Larsen truss panel, for example. Dense-packing the panels off-site will add additional complexity, as will keeping the insulation dry during outdoor storage, transport to site and installation, whether it is dense-packed or batts.

On-site completion: Pre-insulating panels will simplify installation in the field; however, the insulation must be kept dry during transport and installation.

Panel size: The size of I-joist Panels is limited by what is practical to handle in the shop and transport to site. One great advantage of using I-joists to build panels is that they can be purchased in long lengths, easily long enough, for example, to build a panel that can span two or even three stories in height. Both plywood and OSB structural sheathing of any desired thickness can be used.

Cost: The I-joist panels are an inexpensive option, especially when very high R-values are needed. The cost for these panels will vary based on the cladding material used.

Approvals: I-joists are designed to be used in floor systems, not in vertical applications. In particular if the joist is not fully supported across its depth, the weight of the cladding imposes a vertical load that the glue-joint between the OSB web and the outer flange was not designed for. For this reason, the Authority Having Jurisdiction will likely require engineering approval that may be unavailable from the I-joist manufacturer. Fully supporting the bottom of the panel may be sufficient to overcome this concern but it is an issue that should be addressed early in the design stage with the building department and the structural engineer.



6.5 EIFS panels

6.5.1 Overview

The Exterior Insulated Finish System (EIFS) panel is a proprietary panelized system made by a small number of companies. The panel is comprised of EPS insulation board with a reinforced base coat and a textured finish coat, with many colours and textures available. The back of the panels have continuous aluminum receiver channels set into grooves in the EPS made with a CNC hotwire in the factory. A brief description of the panel is provided below, for more details please see Appendix A.

6.5.2 Layer-by-layer assemblies

- Exterior
    - Finish coat.
    - Base coat with reinforcing mesh.
    - EPS board insulation.
    - Air barrier membrane + water resistive barrier.
    - Existing assembly.
- Interior

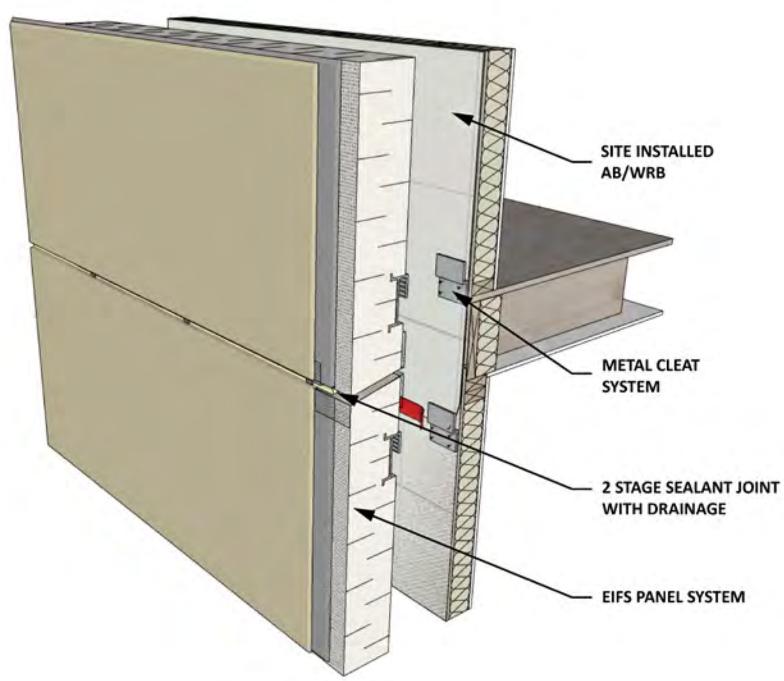


Figure 6-5: EIFS Panel

6.5.3 Differentiating factors

Drying potential: The EIFS panel has a relatively low drying potential due to the thicknesses of EPS insulation that would be typically used and the resulting low vapour permeability. However, there is slightly less risk compared to the full SIP panels due to the absence of the wood sheathing that would typically be found on a SIP panel.

Thermal resistance requirements: Very little thermal bridging through the EIFS panel and the relatively high thermal resistivity of EPS insulation allows this panel to meet thermal resistance requirements with a thinner panel compared to some of the other options.

Embodied carbon: The use of EPS insulation results in moderate embodied carbon. However, this system includes an acrylic plaster as the cladding, which has a relatively low embodied carbon.

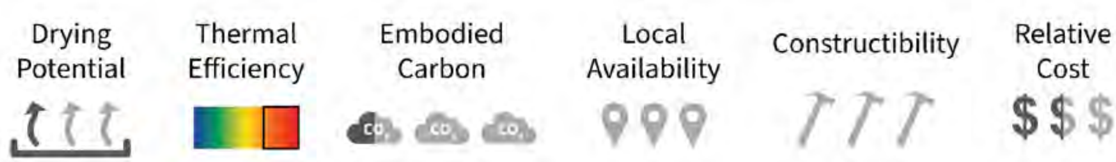
Local availability: EIFS panels will most often need to be transported some distance, as there is limited Canadian manufacturing.

Constructability: EIFS panels are manufactured products and require special tools/equipment, training, and trades. Windows and doors can not be supported by the panel.

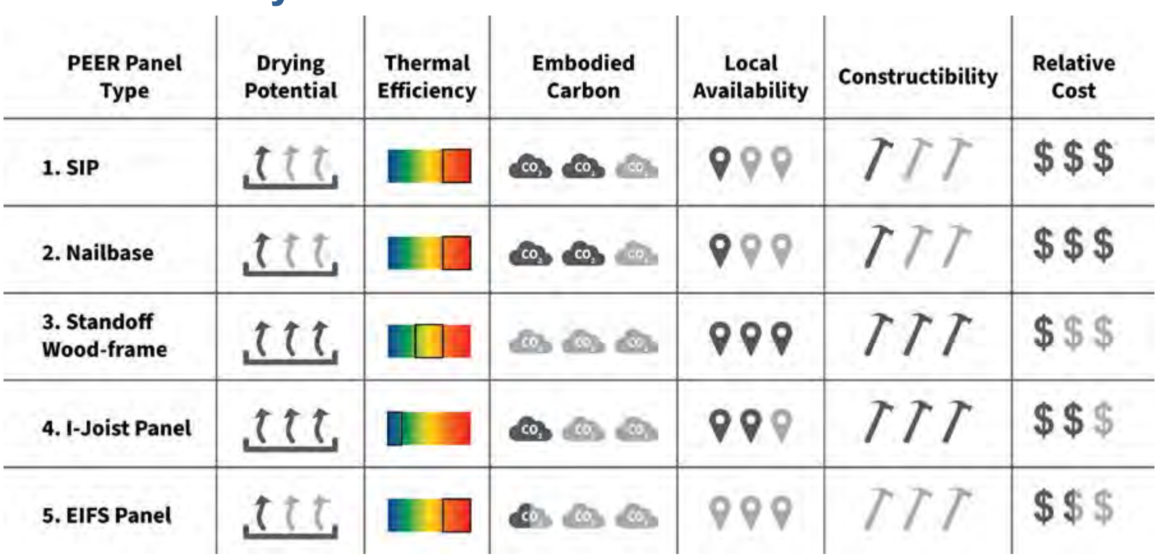
Panel size: Dependent on the specific manufacturers system.

Cost: Prefabrication and shipping costs may vary depending on location.

Approvals: Unlike the other panel options, EIFs panels are a proprietary system designed specifically for use as insulated wall cladding. As such, the manufacturer should be able to provide the building product certifications and engineering approvals required by building officials.



6.6 Summary table



7. BUILDING CAPTURE

To prefabricate retrofit panels off site, detailed building information and accurate measurements of the existing building are necessary. Hand measurements can be time consuming, difficult to capture at height, and in certain conditions can introduce costly errors. New tools and technologies such as 3D laser scanning and photogrammetry are available that allow quick collection of reliable measurement data. For this guide, use of these tools to collect measurements is called “Building Capture”. This chapter describes the technologies and methodologies to acquire reliable measurements and to generate outputs with sufficient resolution and accuracy for panelized retrofit applications. Chapter 8 covers the process or workflow for converting measurement data in the form of point clouds into shop drawings.

Chapters 7 and 8 cover the following steps:

- Planning;
- Data Acquisition (Field Work);
- Data Processing (Office Work);
- Production of “as-found” documentation (optional);
- Panel design and production of shop drawings;
- Sharing and disseminating information.

7.1 Benefits of a digital building capture approach

The benefits of a digital building capture approach are:

- Can capture key measurements from a distance with minimal impact on occupants;
- Can capture measurements of upper story openings without the need for scaffolding or lifts;
- Can capture accurate roof dimensions and slopes;
- Can simultaneously capture other relevant building and site information;
- Can help to identify inconsistencies and irregularities in the building (i.e., out of plumb, out of level);
- Reduced risk of data entry error;
- Data can easily be distributed and shared with various project stakeholders;
- Panel drawings can be easily checked against point clouds and other digital measurements in the office as a QA step prior to releasing for production.

7.2 Possible drawbacks of a digital building capture approach

The potential negative aspects of a digital building capture approach are:

- Data can be inaccessible without specialized software and skillsets;
- Difficulty in finding service providers;
- Cost can exceed traditional methods;
- High cost of tools and software.

7.3 Definitions

The following terms related to building capture are defined below:

- **Accuracy**—the degree to which the resulting measurement conforms to the true value;
- **Building Capture**—the overall process for obtaining measurements, processing the measurement data, and representing in a format suitable for panel design and fabrication;
- **Calibration**—systematic reduction of measurement deviations by correlating instrument readings with precise reference values; in 3D laser scanning this refers to the calibration of equipment and instruments; in photogrammetry this refers to the measurement and software offset of camera lens distortion to improve accuracy;
- **Coordinate System**—a common 3D framework for a single measurement or group of measurements—expressed as X, Y, Z values (Cartesian notation);
- **Key Plan**—floor plans showing primary architectural elements of each building by floor level. They graphically represent walls, doors, windows, room numbers, and other features;
- **Local Grid**—measures positions on a site relative to a point placed on site. All measurements are therefore relative to this datum;
- **Measured Accuracy**—the degree of deviation relating to the measurement data; in 3D laser scanning this is primarily affected by the standard deviation of the equipment's sensor, the way in which the measurements are joined into a single coordinate system, the angle of incidence, surface reflectivity/colour/ roughness, the level setup of the instrument, and subtle movement or displacement of the instrument during scanning,
- **Measured Drawings**—drawings prepared from on-site measurements of an existing building to be retrofit (not to be confused with As-built Drawings which are those prepared by a contractor as it constructs a building, or Record Drawings which are a compendium of the original construction drawings, site changes, and information taken from the contractor's as-built drawings),
- **Origin**—the central point within a Coordinate System defined as 0,0,0,
- **Panel Key Plan**—shows the location of each panel by number,
- **Point Cloud**—the digital 3D dataset generated by a laser scanner or photogrammetry software,
- **Precision**—the degree to which similar or repeated measurements show the same results. A good measurement system has both good precision and good accuracy,

- **Represented Accuracy**—the accuracy of a representation or drawing as construed or interpreted from the measurement data, independent of measured accuracy,
- **Resolution**—in 3D laser scanning, the distance between two independently measured points at the object's surface; usually expressed at a specified distance (e.g., 6.1mm @ 10m). It is important to understand that resolution will vary within a point cloud depending on:
  - the distance between the scanner and measured object, and
  - the degree of overlap between individual scan stations.
- **Tolerance**—the amount of allowable variation between a physical dimension and a specified value (e.g., +/- 5mm).

7.4 Critical measurements, site information, documentation

The following sub-sections outline some of the key information and dimensions required for a typical panelized retrofit project, and how best to record and communicate that information.

7.4.1 Site photographs

Photographs of the building and site are valuable regardless of the choice of building capture methodology. Any conditions that may affect panel design, fabrication and installation should be photographed. Examples include:

- Registration or control targets used in building capture;
- Building elevations from various locations and angles;
- Existing building enclosure materials and their condition;
- Unique building features;
- Close-up detail photographs at roof, window & door openings;
- Service entrances and meters (gas, water, electrical, air conditioning);
- Wall and roof mounted equipment and accessories (satellite dishes, antennas, air conditioning units, mailboxes, electrical devices, hose bibs, etc.);
- General site conditions (trees, plantings, utility lines, fences, wooden decks, stairs, handrails, accessory buildings, obstructions, mechanical equipment, etc.);
- Roof, soffit, eaves, and downspout conditions.

File naming of the photographs should include a brief description and the location of each photograph and should be referenced to a site plan or building key plan. Time spent taking and organizing photos will likely be saved when detailing the panels.

7.4.2 Site plan and key plan

A **site plan** is a 2D (in some cases 3D) representation of the building site. It will indicate the building footprint, any site obstructions (large trees, overhead wires, neighbouring buildings) and the location of scan stations and photographs. **Key plans** are individual floor plans showing primary architectural elements for each floor that will be retained and will be necessary for panel design. The pertinent features of a key plan include the perimeter of the exterior of the building and window and door locations.

Figure 7-1: Site Plan referencing location of scans and photos

7.4.3 Critical measurements and required accuracy

Figure 7-2 below illustrates critical dimensions that need to be accurately captured and represented in order to design retrofit panels for a typical row-home.

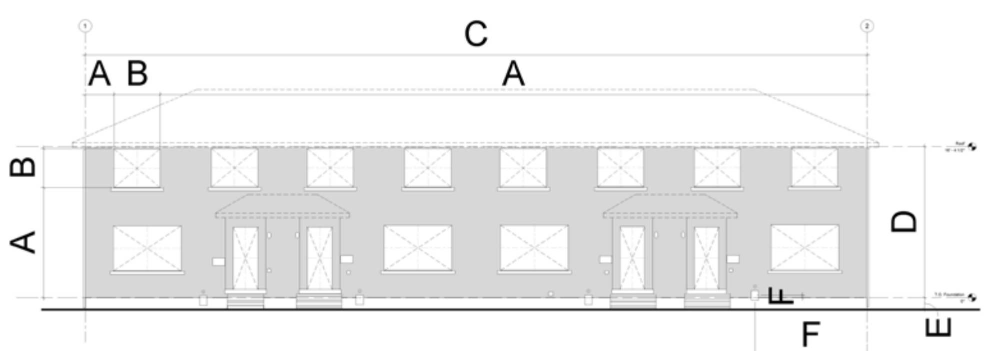


Figure 7-2: Critical Measurements

Figure 7-2 suggests a degree of accuracy or maximum uncertainty that may be acceptable. This will vary according to panel type, its ability to accommodate anomalies, and the panel fit strategy. It is important to consider sources of error and uncertainty and how much tolerance a panel design can accommodate and still fit in the field.

Table 7-1: Critical Measurements and Example Measurement Tolerances

Measurement / Dimension		Tolerance	
		(in)	(mm)
A	Position of window opening in façade (X, Y)	¼"	6
B	Window and door rough opening (height and width)	½"	12
C	Overall building width	¼"	6
D	Overall building height from top of foundation to underside of soffit	1"	25
E	Average grade level to top of foundation	1"	25
F	Centreline of building penetrations, utility meters, and service entrances	1"	25

To derive the rough opening sizes from measurements available from digital capture (the inside of the window frame, outside of brick mold or other prominent edges) it will be necessary to carefully hand measure the window frame profile to establish the relationship between the captured dimensions and the rough openings. This usually requires removing the inside casing. This should be done for both windows and doors. If there is more than one window type, it may be necessary to do so for each.

7.5 Sources of error

Several sources of error may jeopardize accurate measurements. It's important to understand these sources to minimize them where possible, and to build-in tolerances and strategies to ensure panels fit when on-site. Panel-fit strategies are discussed in section 8.1.

Instrument uncertainty
Interpretation error
Manufacturing tolerances + dimensional stability
\+ Installation tolerances

Total Potential Error

7.6 Building capture technology and methodology

7.6.1 Hand measurements

To accurately scale a 3D photogrammetric model, baseline measurements must be established in the field. This can be done by installing a minimum of two fixed reference points (targets) on each building face and taking an accurate measurement of the distance between them. Adding a third target can help establish the vertical axis. Black and white targets are best because they are highly visible in photographs and have a precise intersection point to measure from. Ideally these targets would be placed as far apart horizontally as possible (without introducing tape sag error) to increase the overall level of accuracy. If possible, they should be placed close to the ends of each façade. Measurements can be taken using either a traditional tape measure or an electronic distance measure. Each target should be assigned a unique identifier, and distances between should be carefully recorded (e.g., T001:T002 = 32.450m).

To accurately level a 3D photographic model, a proper z-axis (vertical) must be established. This can be achieved by installing two vertically aligned targets using a plumb bob or other reliable instrument that can establish a plumb line. An accurate measurement between the vertically aligned targets should also be recorded to facilitate proper levelling of the photogrammetric model.

For panelized retrofits, it is important to keep in mind that many existing buildings will not be level nor plumb. It may be preferable to establish a datum and baseline from the foundation or floor system and the vertical axis as perpendicular to this as co-planer to the building face as possible.

7.6.2 Survey Control Network: Total Station Survey

A far more efficient and accurate alternative to hand measurements is to use a total station to capture 3D coordinates of each of the black and white targets installed in the field. A total station is a surveying instrument that combines the functionality of an electronic theodolite (or transit) with electronic distance measuring capabilities, and advanced software. They measure angular rotation and distance to determine the position of a point in space. Such surveying services are readily available in most regions and this work could be carried out by a local surveyor or an in-house field technician. The cost of total stations is relatively low, and basic operations are straightforward.

These instruments are extremely accurate when used correctly. For example, a one second of arc instrument would achieve a positional accuracy of about 1 mm from a distance of 200 m with as little as 1 mm ± 1ppm of distance error. An additional benefit of using a total station survey is that it can help to ensure that other data collected in the field is both dimensionally and spatially accurate.

Where a surveyor is hired to carry out the work, the following general approach can be used:

- Install a minimum of two labelled black and white targets on each building face prior to the surveyor arriving on site. Clearly label the targets (e.g., T001, T002, T003, etc.).
- Provide the surveyor or field technician with the municipal address, general site photographs, and an approximate number of targets to be observed. This will help them to estimate the level of effort and cost of the work.

- Install a clearly marked "origin" target on site, label it T000 (or similar) and ask the surveyor to assign this as the origin point for the coordinate system. Ideally the origin target would be located near the South-West corner of the building.
- Specify which face of the building the coordinate system should be aligned to, bearing in mind that this will determine the orientation of your 3D models.
- Ask that Local Grid coordinates be provided for each target in 'tab delimited' .TXT format as follows:

Point#	Easting	Northing	Elevation	Comment
T001,	61.256319,	46.178799,	14.632597,	south facade–east,end
T002,	60.664522,	89.936689,	43.659942,	south facade–west,end

Figure 7-3: A Total Station can be used to obtain 3D coordinates of discreet points (i.e., building corners, window openings, etc.) or targets.

Figure 7-4: A survey control network is projected onto a point cloud to see its relative position in 3D.

7.6.3 Photogrammetry

Photogrammetry is a process whereby extremely detailed and accurate 3D models can be generated from a series of photographic images. The primary drawback of using only photographic images in architectural photogrammetry is that the resulting 3D models are without scale and precise reference to level. When combined with accurate measurement data, the results can be extremely reliable.

Some key advantages of photogrammetry are the accessibility of the technology, relatively low equipment costs, and minimal skill required for data capture.

Although nearly any digital camera setup could be used, best results will be achieved with a high-end digital SLR camera with a fixed, prime lens. For architectural applications, a wide-angle lens is usually preferable (20 mm, 28 mm). A full frame camera will produce better results but will also require more computer processing power. A fast lens (f1.8 or better) will allow for sharp images in lower light conditions. Using the Aperture Priority setting at f/5.6–f/8.0 is preferable and will help to ensure that all building features are in sharp focus and that there is no pronounced depth of field in the images. Generally speaking, most automatic features and image manipulation should be disabled on the camera (i.e., Vignette Control, Active D-Lighting, Auto White-Balance). Manual White-Balance should be used to ensure consistent colours. A tripod should be used where possible as sharp images are critical in achieving quality results.

The data capture process involves taking a series of overlapping photographs around the perimeter of the building. In general, each photo should have a minimum of 60% overlap with the previous photo, and a maximum of 10-15° rotation. For best results, a full closed loop of the building should be completed in a continuous sweep, with a photograph taken every two or three feet. Err on the side of taking more photos, as this will help to ensure sufficient overlap and some level of redundancy in the event that a poor-quality photograph is taken. The transition around corners of the building should be gradual, with no sharp or sudden changes in the angle that the photos are taken on.

Once captured, the resulting series of photographs can be input into photogrammetric software to generate a complete 3D model of the building. If the photographs were taken in a very careful manner, some software may be able to produce a detailed 3D model with little or no additional operations necessary. In other software, discreet points can be selected from multiple photographs to build a wireframe model.

Once processing is complete, the target coordinates provided by the surveyor can then be input into the photogrammetry software to establish the scale and orientation of the model.

Remotely Piloted Aircraft Systems (RPAS, also commonly referred to as drones) with built in cameras can also be utilized to capture photographic data in areas that are difficult to capture from grade, such as upper storey windowsills and roof lines and the facades of mid and high-rise buildings. This type of equipment is relatively inexpensive, and many models have high quality cameras built in that are well suited for photogrammetric applications. In Canada, all operators of RPAS must carry a valid drone pilot certificate issued by Transport Canada.

Figure 7-5: Photographic data being captured by digital SLR and by drone for photogrammetry model.

7.6.4 3D LiDAR scanning

3D Laser Scanning or LiDAR is a technology used to rapidly collect dimensional information of objects occurring in the scanner's immediate environment. There is a range of scanners on the market geared towards different applications. 3D laser scanning is commonly used in mining, manufacturing, reverse engineering, forensics, engineering, and architecture.

For architectural applications, terrestrial (or stationary) scanners are most common. These scanners are characterized by a motorized mirror spinning on the vertical axis. The mirror reflects the laser outwards towards the environment and the entire scanning head turns on the horizontal axis. As the laser encounters objects, it reflects back to the scanner head which calculates distance based on time-of-flight or phase-shift technology (depending on the scanner). A complete rotation in both axis results in a dome-scan, usually comprising tens-of-thousands to millions of xyz points in space. The resulting xyz dataset is referred to as a point cloud. Some scanners come equipped with colour cameras that can augment xyz spatial data with rgb colour values. Unlike total stations, laser scanners are non-discriminatory and capture all objects within tolerable reach.

Scanning is usually conducted at multiple locations or stations around the desired building. Combining and aligning individual scans together into a single coordinate system is called scan registration. Scan registration is performed on or off-site using software. Some software applications require that targets be introduced into the scene to aid registration, while other software applications support targetless registration; whereby overlapping features in two or more scans are identified, essentially using features in the scene itself as targets. Targetless registration saves considerable time on-site as the preparatory stage of setting up physical targets is eliminated. However, targets can be expected to produce better, more consistent results. These same targets can be those used to establish a survey control network.

There are many benefits to laser scanning, including a high degree of accuracy, unmatched detail, rapid workflows, and the ability to model or draft from resulting point clouds directly in common CAD, BIM, and other software applications. Key disadvantages to laser scanning include the high cost of hardware and software, specialized workflows, large file sizes, line-of-sight issues (where portions of architecture cannot be seen or measured by the scanner), and highly reflective surfaces that lasers are unable to capture.

It should be noted that laser scanning and other reality capture technologies are currently the subject of great public and commercial interest and there are significant efforts underway to reduce costs, increase quality, and improve processes. At the time of publication, 3D laser scanning likely represents the most accurate and mature digital capture technology for this application. CanmetENERGY also recognizes that building capture technologies are the subject of rapid innovation. 3D photogrammetry or other technologies may displace laser scanning as more cost-effective alternatives in the future.

Figure 7-6: Field technicians using a 3D laser (LiDAR) scanner to measure an existing building.

This guide proposes three different hybrid methodologies that can be best used for digital building capture for panelized retrofit. Each methodology uses a unique combination of hand (or distance meter) measurements, total station surveying, photography (photogrammetry), and 3D LiDAR scanning. Selecting the methodology that is right for your project will depend on your specific situation and needs. Each methodology will likely require some hand measurements to locate the position of the rough openings relative to geometry that is visible from the point cloud, for example.

Table 7-2 below outlines each of the three methodologies (from least sophisticated to most) and their related equipment, processes, and outputs.

Table 7-2: Comparison of various Data Capture Methods (from least sophisticated to most)

Method	Level Of Accuracy	Time / Effort / Cost	Availability of services	Accessibility of data output	Complexity	Data Capture Processes	Equipment	Outputs	Formats
A	MEDIUM	VERY LOW	HIGH	HIGH	VERY LOW	**SURVEY CONTROL NETWORK**	Total Station and/or distance meter	• Scaled, Measurable, High-Resolution 2D Ortho-Elevations; can be imported into CAD software	.JPG/.PNG
						PHOTOGRAMMETRY	Digital SLR Camera, Fixed Prime Lens, and/or Remotely Piloted Aircraft System	• Colorized 3D Point Cloud generated from Photos; can be imported into CAD and BIM software	.E57/.PTS/.RCS/.RCP
B	HIGH	MEDIUM	MEDIUM	HIGH	MEDIUM	**SURVEY CONTROL NETWORK**	Total Station	• Scaled, Measurable, Low-Resolution 2D Point Cloud Elevations; can be imported into CAD and BIM software	.JPG/.PNG
						TERRESTRIAL 3D SCANNING	Survey Grade 3D Laser Scanner	• Colorized 3D Point Cloud; can be imported into CAD and BIM software	.E57/.PTS/.RCS/.RCP
C	HIGH	HIGH	LOW	HIGH	HIGH	**SURVEY CONTROL NETWORK**	Total Station	• Scaled, Measurable, High-Resolution 2D Ortho-Elevations; can be imported into CAD software	.JPG/.PNG
						TERRESTRIAL 3D SCANNING	Survey Grade 3D Laser Scanner	• Colorized 3D Point Cloud; can be imported into CAD and BIM software	.E57/.PTS/.RCS/.RCP
						PHOTOGRAMMETRY	Digital SLR Camera, Fixed Prime Lens or Remotely Piloted Aircraft System		

7.7 Data formats

Data formats are dictated by both building capture process and panel design workflow.

7.7.1 Point clouds

A point cloud is comprised of tens-of-thousands to millions of xyz points in space that represent the surface of a 3D shape—for PEER, this is a building and its surroundings. Point clouds can be generated by laser scanners and by photogrammetry software. Some laser scanners come equipped with colour cameras that can augment xyz spatial data with rgb colour values.

There are hundreds of file formats for 3D modelling. The number of point cloud file formats that can be used in CAD and BIM is also growing. The most common groups of formats are:

PTS, PTX, XYZ—there are common formats that are supported by most BIM software and are easily converted and manipulated;

PCG, RCS, RCP—are proprietary Autodesk formats and are compatible with Revit and Recap but not applications outside of Autodesk;

E57—is a vendor-neutral file format for point clouds with capability to store images and metadata. It is compact and widely used.

The variety of file formats can introduce compatibility challenges for modelling workflows. Panel designers should be careful when conducting or commissioning building capture services to make sure that they receive or create files that will be compatible with the software and workflows they plan to use.

Table 7-3: Point cloud formats

Panel Design Software	Autodesk Revit	Autodesk Recap	Cadwork
File Format			
E57		X	X
PTS		X	X
LAS		X	X
RCS	X	X	
RCP	X	X	

7.7.2 Total station measurements

Most total stations are capable of converting spherical survey coordinates to Cartesian spatial measurements and record these as xyz data. In surveyor parlance, the x-axis is the Easting, y-axis is the Northing, and z-axis is the Elevation.

Total stations may export 'tab delimited' .TXT format of local grid coordinates, which can be imported into the modelling environment.

Local grid coordinates can be provided for each target in 'tab delimited' .TXT format as follows:

Point#	Easting	Northing	Elevation	Comment
T001,	61.256319,	46.178799,	14.632597,	south facade–east,end
T002,	60.664522,	89.936689,	43.659942,	south facade–west,end

7.8 Building capture outputs and as-found documentation

Some panel design processes, and software may be limited to working in 2D. All the building capture methods outlined in Table 7-3 are capable of producing scaled, measurable 2D ortho-elevations. These can be imported into CAD software to model each building elevation or directly develop panel shop drawings.

Figure 7-7: Scaled, measurable 2D ortho-elevations can be imported into CAD software

Figure7-8: 3D pointclouds can be imported into BIM and CAD software.

In most cases, however, the preferred output of the building capture process will be a colourized 3D point cloud. Point clouds can be imported natively into most BIM software and modelling can take place directly over the point cloud.

Panel design workflows may involve first modelling the existing building to represent as-found geometries. This may be useful for generating energy models or permit documentation. Computer modelling of the building is a traditional part of the workflow for many building capture applications; however modelling is time-consuming, costly, and generally sacrifices project accuracy in one way or another. By modelling manually, a technician must interpret data points in the point cloud and convert these into linework in a CAD (computer-aided design) or BIM (building information modelling) environment. This interpretation can lead to error. Progressive companies and software vendors are increasingly looking for ways to capitalize on using the point cloud directly, thus eliminating modelling from the workflow. A panel fabricator could use software such as AutoCAD or Revit for example, to design panels directly on top of a 3D laser scanned point cloud to produce shop drawings. Some modelling will likely be necessary to represent required demolition that needs to take place after data capture and before panel installation, but the very need to generate a digital twin of the building should be examined.

An efficient building capture process will collect all necessary information while on site and not waste time and money with superfluous modelling of irrelevant information and extra detail.

8. PANEL DESIGN AND DRAWING

Once designers have an accurate 2D ortho elevation or 3D point cloud or 3D model to work with, an application such as Autodesk Revit can be used to quickly and efficiently extract key information in which to base their panel layout and design. Supplementary videos of this workflow using Revit can be found here. Canadian panel fabricators often use specialized software such as Cadwork or StrucSoft for producing fabrication documents. Cadwork includes a module called Point Cloud, to model directly on the point cloud. StrucSoft MWF Pro Wood is a Revit plug-in that allows its users to automate the design of framing members and other layers and to produce 2D construction documentation. CanmetENERGY and ReCover have developed a prototype workflow using Cadwork and LexoCad.

01–Create New Project

- Open the application and set up a new project with your preferred unit of measurement.

02–Import Point Cloud

- Click on **Insert > Point** Cloud and navigate to the .RCP point cloud file.
- Once imported, pin the point cloud in place to avoid accidental misplacement.

03–Setup Elevation Views

- Use Revit to establish the location and direction of elevation views for each building face. Locate the preferred cut plane and establish clipping depth.

04–Move Elevation Datums

- In elevation view, move the Level 1 datum line to align with the top of foundation and the Level 2 datum to align with the underside of soffit (or other relevant location).

05–Rename Elevation Datums

- Rename the Elevation Datums accordingly.

06–Create New Wall Type Assembly

- Use Revit to build up a new wall assembly with the desired properties, materials, and thicknesses.

07–Draw New Walls Around Building Perimeter

- Draw new walls around the building perimeter ensuring that the location line setting is set to ‘Finish Face: Interior’.
- The ‘top of foundation’ and ‘underside of soffit’ datums can be used to set the Base and Top constraints of the walls.

08–Verify the Placement of New Walls

- Use section cuts to inspect the vertical placement of the walls.
- Use plan views to inspect the horizontal placement of the walls.

09–Create wall openings

- Create new wall openings using the underlying point cloud as a guide.
- Similar openings can be created by copying or mirroring.

10–Add Panel Reveals and Divisions

- Reveals can be used in Revit to establish panel break lines, tolerances, etc.

11–Dimension Panels

- Dimensions can be used in Revit both to modify and manipulate wall geometry, and to communicate key dimensional data.

12–Setup Drawing Sheets

- Once critical dimensions and all necessary annotations have been added to each of the elevation views, scaled viewports can be added to drawing sheets for output to CAD or PDF format.

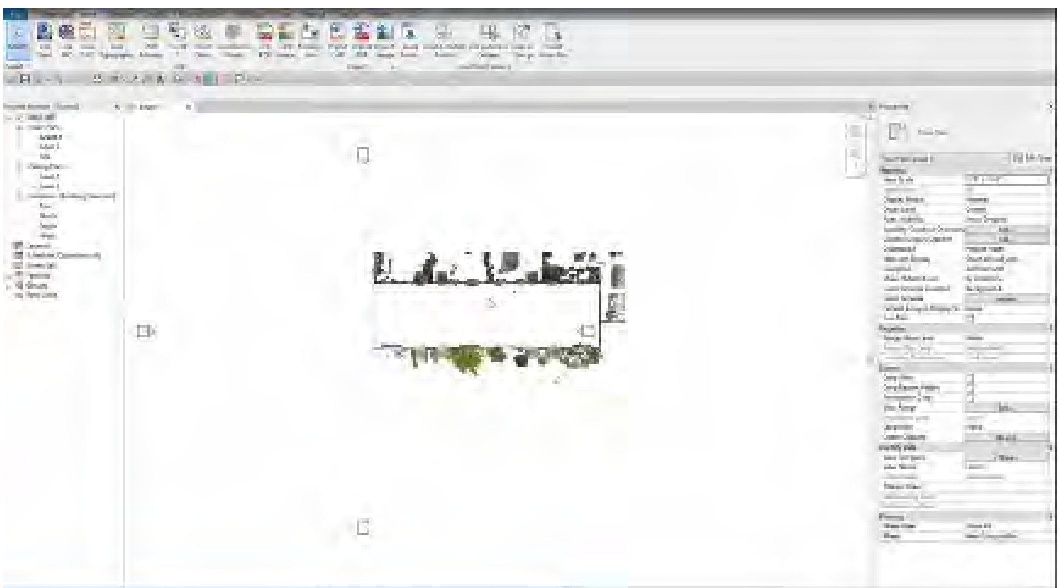


Figure 8-1: Step 2—Import Point Cloud into Revit environment:

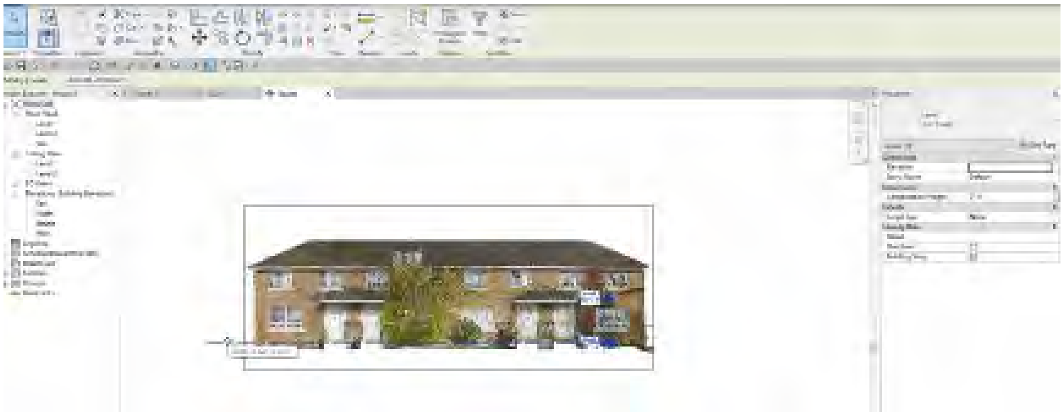


Figure 8-2: Step 3—Setting up elevation views

8.1 Panel fit strategy

Some tolerance for error can be designed into the panels to reduce the risk of panels not fitting the existing building and the need for on-site modifications. This provides some accommodation for misalignment.

For example, new windows can be made smaller than the original openings to ensure an easy fit. Note that this is typically not possible for exterior doors because doors are only available in certain sizes. For this reason, entry doors (and service penetrations made in the factory instead of on-site) may be the most critical dimensions and may dictate panel positioning.

8.1.1 Windows

As noted above, window openings can be made slightly smaller than the existing rough openings, provided building code egress requirements are not affected. This provides some room for panel error and helps ensure that the panel window openings are within the existing openings.

For the OCH project, windows openings were reduced by 50mm (2”) on all four sides. The rough opening was shimmed as necessary to support a finished plywood jamb extension. The interior was finished with picture frame casing.

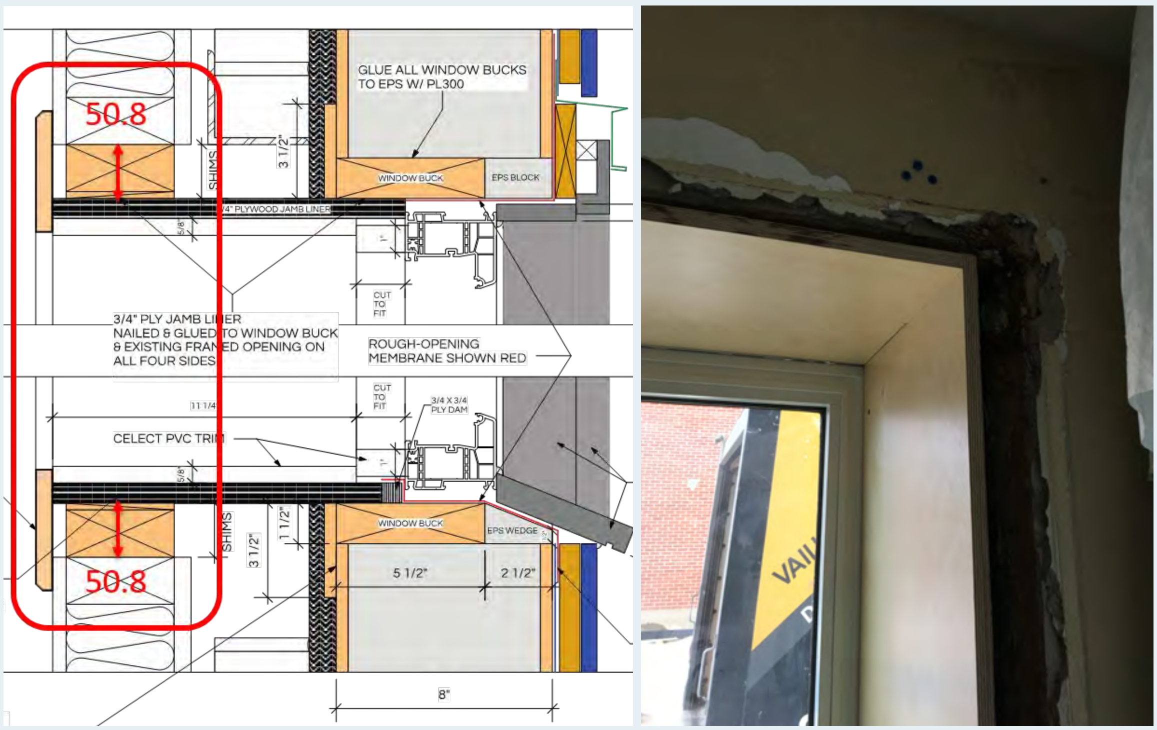


Figure 8-3: (left) vertical section depicting window fit strategy. (right) jamb liner (extension) viewed from the interior

8.1.2 Vertical panel joints

Depending on how they are detailed, vertical joints can grow or shrink in width to accommodate some lateral adjustment when placing panels. The space between panels can be filled with expanding polyurethane foam, a compressible gasket or a custom ripped filler strip and sealant. The panel joint cavity should be filled to minimize convective looping. Particular attention to air sealing panel joints is covered in Section 10.6 below. Note that panel length can strongly affect building aesthetics. For example, if horizontal cladding is used and the panel joints require a vertical cover strip, the choice of panel length will be critical to achieving a pleasing design.

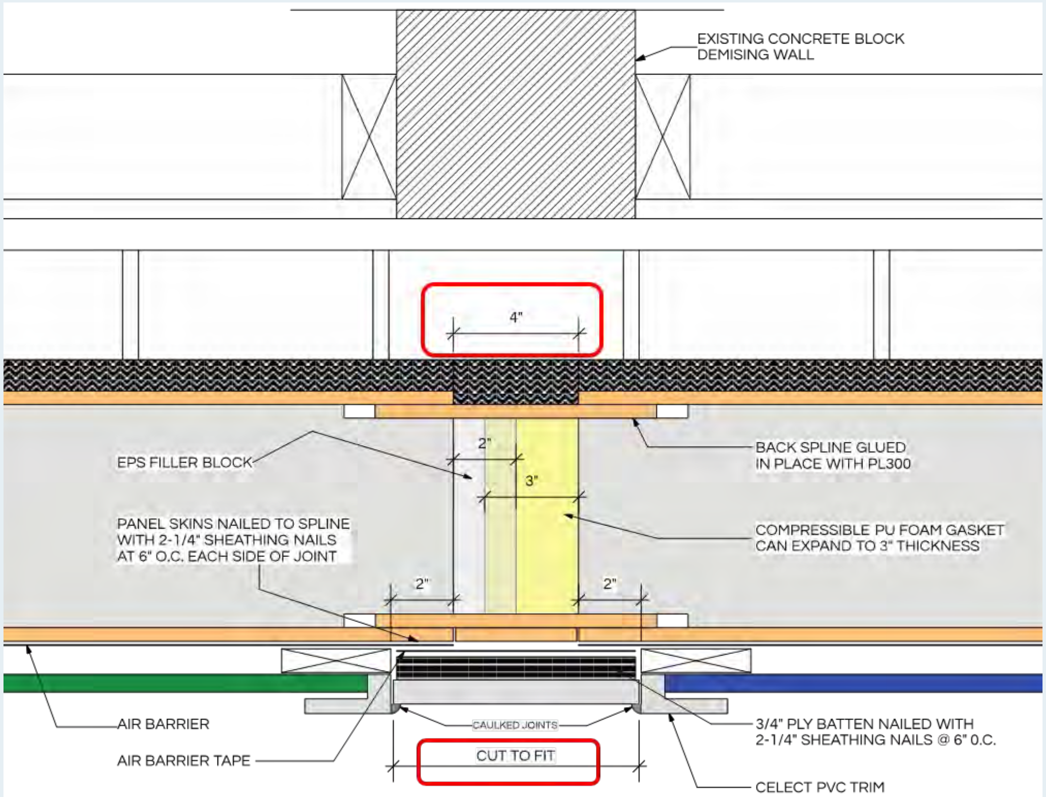


Figure 8-4: Vertical panel joint

OCH vertical panel joints included a nominal 100mm (4") space between panels. Panels were connected with splines inserted into a rebate in the foam. A low-density gasket material was specified to fill the cavity. The gasket could easily compress or expand to provide ± 25mm (1") of lateral adjustment for each panel. A trim element was ripped onsite to the final width needed to finish the joint.

9. PANEL FABRICATION

In Europe, fabricators are beginning to use mass customization to automate panel production. Once a market is established, this may well be possible in Canada. This guide, however, will focus on manual processes for small to mid-size panel fabricators for the first generation of projects.

9.1 Shop requirements and degree of sophistication

Little investment is necessary to begin operations and exploit the benefits of off-site construction. A basic panel fabrication workshop might consist of the following:

- An enclosed space with minimal obstructions, with a flat and level floor, to provide shelter from the elements;
- Good overhead lighting, power supply and compressed air supply;
- Elevated framing tables for working at a comfortable height;
- A chain hoist or other means for moving and manipulating heavy panels within the shop;
- Reliable power supply sufficient to simultaneously run compressors, saws etc.;
- Covered area for storing building materials and completed panels.

Ottawa Community Housing built their own shop to fabricate their panels. The OCH shop dimensions were 32'x32'x12' high. Two shipping containers lined either side and provided a secure place to store tools. A 10'x18' rolling table could be moved within the shop. The table included a removable centre to facilitate cutting out window and door openings

Figure 9-1: OCH fabrication shop

Larger projects may call for more sophistication and mechanization. This is outside the scope of this guide.

9.2 Fabrication methods

Specific fabrication methods and sequence will vary according to panel type and details, tools at hand, shop set-up and the expertise of the team. The generic process used for three panel types are outlined below.

9.2.1 Wood-frame standoff panel

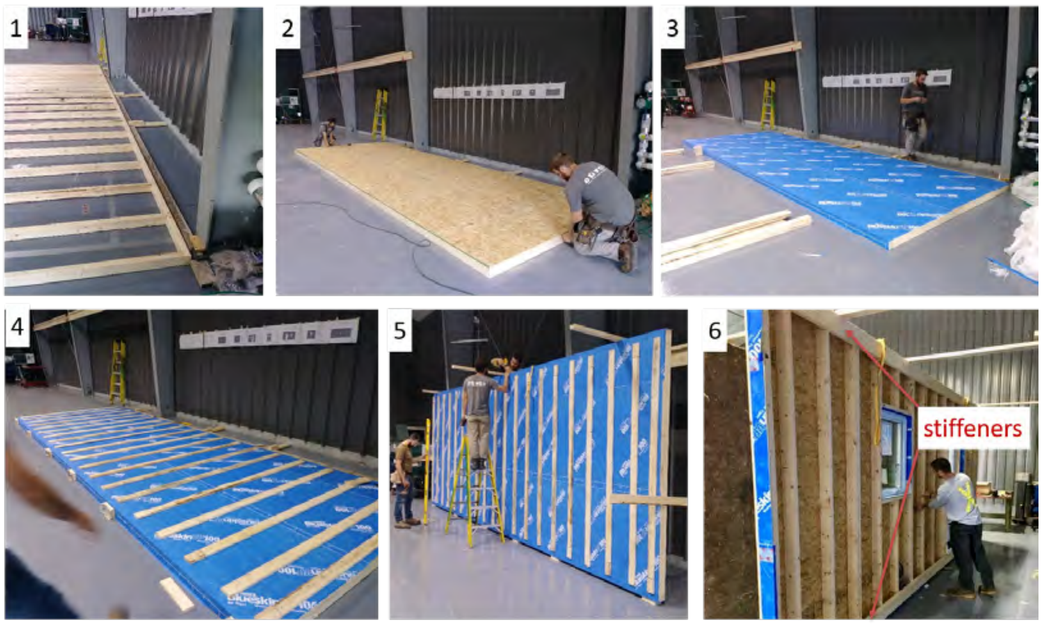


Figure 9-2: Wood-frame Standoff Panel fabrication sequence

1. Plates and studs are connected on a table or flat floor against a straight/square jig.
2. Sheathing is nailed off.
3. Self-adhered WRB/AB is installed, rolled, wrapped and shingled into openings and onto panel edges.
4. Furring strips installed to provide capillary break and rain screen. Furring held back from edge to provide taping surface.
5. Panels stood up for window and door installation.
6. If using large panels (the one pictured is 25’ long), additional framing lumber installed on edge can be used to stiffen the panel. Lifting straps are installed.

9.2.2 Rigid foam nailbase (single sided SIP) panel

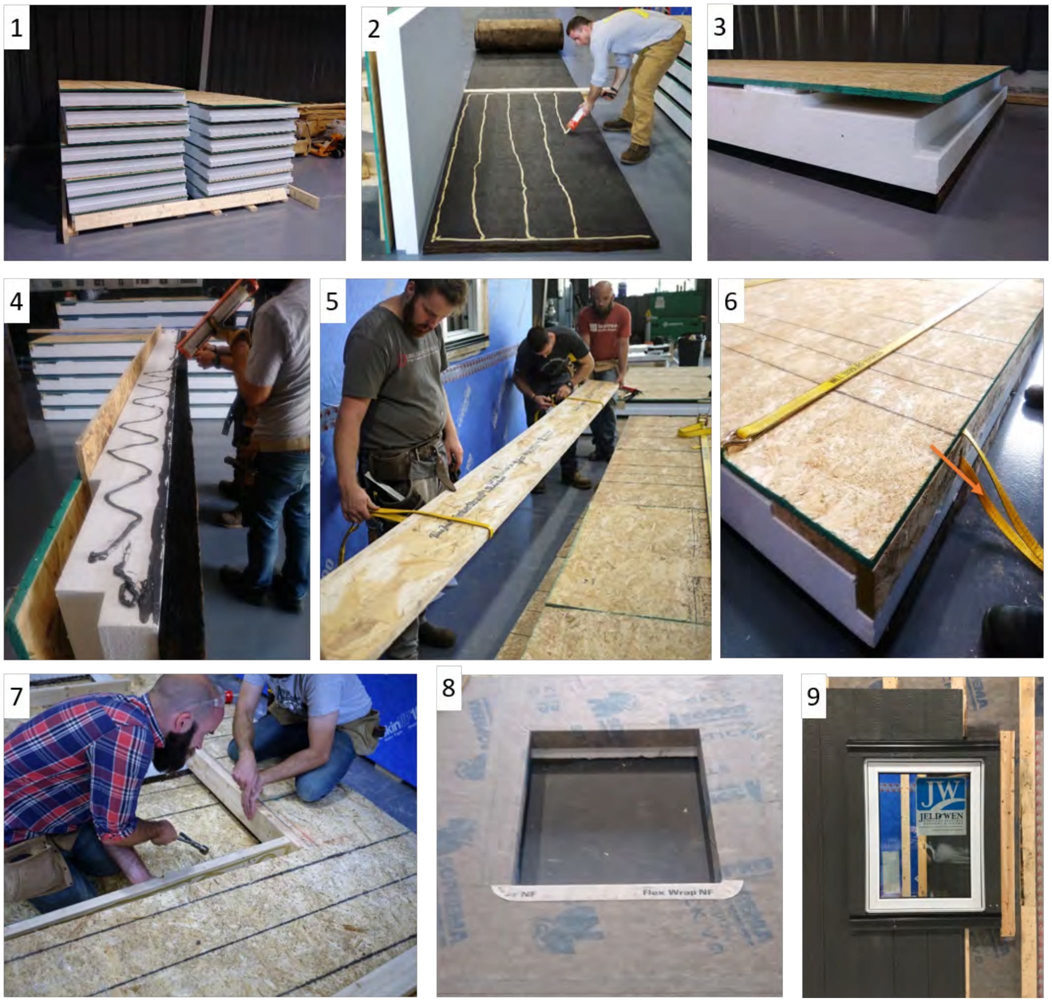


Figure 9-3: Nailbase panel fabrication sequence

1. Base panels received from manufacturer with sheathing pre-laminated and foam CNC hot-wire cut to receive splines and structural members.
2. “Squishy layer” adhered with foam compatible adhesive.
3. Base panels ready to be assembled into “super panels”.
4. OSB splines inserted and foam-compatible sealant applied to butt joints.
5. Lifting straps wrapped around or through pre-drilled holes in structural members before inserting into panels.
6. Ratchet straps used to pull panels tight.
7. Window openings cut with beam saw and bucks installed.
8. WRB/AB membrane and sill flashing membrane installed and rolled.
9. Furring installed, panels tilted up, windows set, flashing, trim and siding installed.

9.2.3 Structural insulated panel (SIP)

The finished OCH SIP panels were fabricated from 4x9' base module SIPs. Similar to the nailbase panels, the OCH SIP design utilized additional wood elements (laminated strand lumber (LSL)) to provide structural rigidity to minimize flex, twisting and torquing (Step 3 in Figure 9-4). In addition, the LSL structural elements enable lifting of the finished wall panel via the holes, through which lifting straps can pass.

Figure 9-4: SIP fabrication sequence

1. Base panels received from manufacturer with sheathing pre-laminated, foam CNC hot-wire cut to receive splines and structural members. OSB splines inserted, and foam-compatible sealant applied to butt joints.
2. L-shaped structural elements pre-assembled.
3. Structural elements inserted and fastened.
4. Beam saw used to cut window and door openings.
5. Panel openings being cut.
6. 2"x6" window and door bucks installed and over-insulated.

7. Flashing, air and WRB membranes installed, properly lapped.
8. Pressure sensitive membranes and tapes rolled for proper adhesion.
9. Strapping installed.
10. Siding installed on strapping..

9.3 On-line vs off-line tasks

Framing, sheathing, installing membranes, strapping, and flashing can be performed with panels on the flat in an assembly line. Panels will need to be tilted up to install windows and doors. These tasks (combined with insulating in the case of wood framed panels) likely need to be performed off-line. Some cladding systems may be able to be installed prior to windows. Trim will often be installed last. Some trim elements may be installed in the field. Holes for service penetrations (mechanical hoods, hose bibs, etc.) are often better made in the field once precise panel locations have been determined.

9.4 Manipulating panels

An efficient fabrication workflow will involve no more handling of panels than necessary. Doubtless, however, it will be necessary to move panels around the shop at various stages of completion. This can be accomplished with wheeled outriggers, pulley systems, gantry cranes or equipment such as a forklift.

Figure 9-5: (left) Wood outriggers on castors proved to be an affordable and effective way to move panels for the 2017 PEER pilot (right) OCH used hand chain hoists mounted to runners on a steel C-channel that allowed panels to be easily tipped-up and moved within the shop.

9.5 QA/QC and inspections

CAN/CSA A277-16 specifies an approved in-factory certification procedure that would apply to prefabricated retrofit panels. The Standard provides requirements for:

a. Certification of the factory quality program;

b. Certification of the prefabricated product;

c. Auditing of the factory quality program; and

d. In-factory inspection of the prefabricated product.

The Standard includes requirements for in-factory inspection, documentation and non-compliance and markings. Obtaining this certification may satisfy the AHJ that the retrofit panels comply with building code requirements and do not need to be inspected in the shop.

9.5.1 Airtightness testing in the shop

Airtightness testing of windows and other openings in the factory prior to the installation of trim is possible and could save time and aggravation in the field. This could either be done quantitatively according to ASTM E783 or qualitatively according to ASTM E1186.

Quantitative testing is performed by sealing a chamber to the interior or exterior face of the panel around the opening, supplying or exhausting air from the chamber at a rate required to maintain the specified test pressure, and measuring the air flow lost or gained across the testing chamber. This would be used to ensure the installed windows and doors have been air sealed according to specifications.

Qualitative testing involves subjecting the assembly to a pressure differential and using a smoke pencil, etc. to detect holes in the air barrier continuity. Either method would provide a measure of quality control to ensure defects are found while they are easy to remedy. Calibrated devices can be used for quantitative testing, or a simple wet/dry vacuum connected to an airtight frame aligned with the opening for qualitative testing.

9.6 Opportunities and outlook for automation

This guide is focussed on manual fabrication of retrofit panels. Automation of panel fabrication is seen as key to scaling, however. As described in Section 2.5, standardized, repetitive tasks are most appropriate for automation. Custom layers are disruptive for building component manufacturers with automated production lines. The existing housing and building stock are heterogenous, made up of unique buildings comprised of various materials, with varied upgrades and additions over their lives. This presents a challenge for industrializing retrofit, as the starting point is almost always different from project to project.

However, by carefully examining the retrofit process, some operations can be standardized and automated. Processes can be broken down into three categories:

Table 9-1: Process suitability for automation

Structured	A defined process that can be automated with standard automation practices
Semi-Structured	A process that is less well defined and more manual dependent
Unstructured	No real process, much more dependent on manual intervention and interpretation

Currently, manufactured panels (prefabricated panels produced with automated machinery) do not typically include membranes, windows, and cladding. These processes are less structured and are difficult to complete “on-line”. Manufacturers are unlikely to invest in new automation processes unless the market is large and the business model is certain. For these reasons, panel manufacturers are currently deemed to be poorly suited for producing finished retrofit panels. However, these companies may supply a manufactured base panel that could be manually finished by others.

New technologies on the horizon may enable “mass customization” of retrofit panels. Two main opportunities have been identified:

1. Automated workflows for converting point clouds into documentation for fabrication (shop drawings and cut lists);

2. Generation of machine files for automated fabrication processes (computer numerically controlled (CNC) or robotic).

This is an area of active R&D, and many Canadian and international companies and universities are working to develop solutions to exploit these opportunities. This evolving field will play an important role in achieving cost-effective, industrialized retrofit methods that can be scaled. The authors of this guide recommend continued R&D investment to adapt these advancements for retrofit applications.

10. PANEL INSTALLATION AND FIELD WORK

The simplest, least disruptive, and most durable approach to deep retrofit is all exterior. Work below grade and above the roofline is beyond the scope of this guide. However, in most cases, it is assumed that PEER wall retrofits will be accompanied with a foundation and roof retrofit.

Interior basement retrofits may also be possible to avoid expensive excavation. However, for most projects, this guide assumes that the foundation and roof structure will be retrofitted from the exterior.

In certain instances, it may be possible to maintain the existing eave and rake elements. This is particularly attractive in buildings with a raised heel that may afford sufficient insulation at the eave, and deep overhangs that will still provide sufficient protection of the thicker, retrofit wall assembly. In this case, the existing ceiling plane may serve as the air barrier. The wall panel air barrier should connect at the top plate.

10.1 Site preparation and demolition

Site preparation includes removing landscaping and obstructing structures.

A panelized approach can reduce the amount of required demolition. For instance, for the OCH pilot, the existing brick veneer and asphalt shingles were retained. This minimized demolition labour and kept these materials out of the landfill. However, some demolition of may be unavoidable, such as:

- Exterior amenities such as porches, decks, fences, awnings, satellite dishes, light fixtures;
- Cladding (in part or entirely) to facilitate structural connections;
- Window and door sills;
- Existing windows and doors;
- Eave and rake overhangs.

10.2 Transporting panels to site

Finished panels with windows, doors, siding, and flashing should be stored and shipped vertically to avoid damage to windows and finishes and should be covered and protected in transit. Unfinished panels can be transported horizontally.

10.3 Minimizing need for scaffolding

Scaffolding is time consuming to erect and cumbersome to install panels around. Its very need should be carefully examined. Fully finishing panels in the factory will ensure that minimal exterior work at height is needed on-site. If site conditions allow, this remaining work (i.e., to seal panel joints or install trim) may be performed using a mobile lift.

10.4 Hoisting panels

A crane, rotating telehandler or boom-truck with a spreader bar is recommended for lifting panels. Although OCH used a conventional telehandler, it did not provide sufficient control to adjust panels laterally. It was also unstable on an icy site

Figure 10-1: A crane proved to be more flexible and faster than a telehandler for hoisting panels for Ottawa Community Housing (OCH)

10.5 Coordinating with other trades and services

Achieving an airtight envelope is critical for realizing energy goals, but also for ensuring long-term durability. Other trades (electrical, HVAC, plumbing, etc.) need to understand the importance of the air barrier. Providing clear instructions (both on plan and on-site) about how and where their penetrations can be made is imperative. It is recommended that there be an "air barrier boss" on-site during construction to coordinate with trades and to problem solve tricky details as they arise.

10.6 Completing air-sealing

Panel joints need to be air-sealed in the field. This can be completed with tape, gaskets or backer rod and sealant. Once air barrier connections are made, an airtightness test can be performed, and any defects addressed prior to trim installation.

10.6.1 Taped Joints

If the WRB is serving as the panel's air barrier, then vertical and horizontal panel joints can be taped in the field. It is critical to roll or press pressure-sensitive acrylic tapes to ensure adhesion. The siding needs to be held back sufficiently for the tape to lap onto the WRB and to accommodate a roller. The gap can be covered with a trim element, applied in the field. The advantage of a taped joint is that it can be inspected and accessed if there is a deficiency. The downside is the obvious trim element at each joint and the aesthetic implications. Membranes and tapes should be compatible, Canadian Construction Materials Centre (CCMC) approved, and installed in accordance with manufacturer's recommendations.

If an exterior air barrier is employed, it is advisable to stop free air movement (convective looping) within an empty joint cavity joint by filling it with insulation. Otherwise, there's a possibility of warm, moist interior air finding a path through the existing wall assembly and water vapour condensing on the back of the tape. Employing vapour permeable tape can help reduce this risk

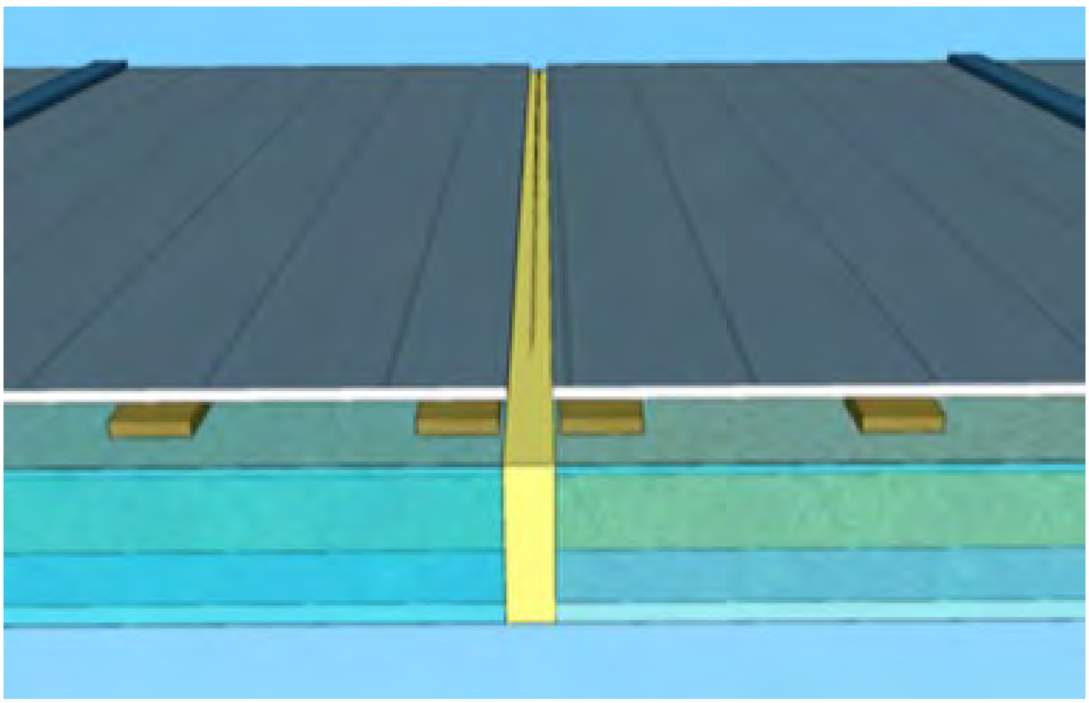


Figure 10-2: Taped vertical panel joint viewed from above. Note the gap in the siding to accommodate a narrow roller. This gap is covered with a trim batten in the field.

Figure 10-3: Pressure-sensitive acrylic tape being used to seal horizontal panel joint in the field.

10.6.2 Gasketed Joints

The authors have not had any experience with gaskets for air sealing retrofit panel joints. However, these are commonly used for sealing joints in panelized new construction. With a pre-installed gasket, it is not necessary to access the air barrier layer in order to seal in the field. This enables panel designs with continuous insulation outboard of the air barrier layer. It also means that cladding can be flush with the panel edge, resulting in a less obvious, architecturally expressed panel joint. Gaskets of various size can accommodate some degree of lateral panel adjustment but offer less tolerance than a taped joint. Note that soft rubber gaskets can be easily damaged and must be protected during panel handling and transport to site or installed on-site prior to panel installation.

10.7 Finishing panel joints

Factory-clad panel joints may be finished on-site with a cover strip. If using lap siding, it may be possible to site-install the top and bottom course of siding at a horizontal panel joint and weave them together. This eliminates the horizontal trim element for a more uniform appearance. Use of a gasketed joint may permit eliminating the vertical cover trims as described above.

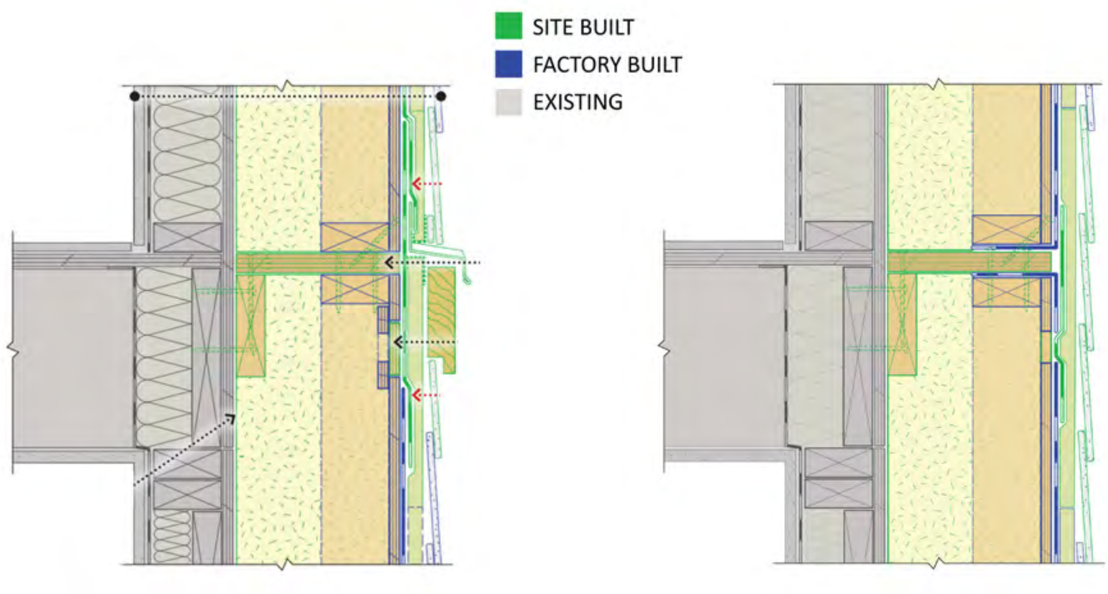


Figure 10-4: (Left) A site-applied trim strip and flashing can be used to finish horizontal panel joints in the field or (Right) lap siding may be woven together to finish the joint in the field.

Figure 10-5: Butterwick Projects finished the horizontal panel joints on site by weaving lap siding together from the top and bottom panels together.

10.8 Finishing window and door openings on the interior

One of the few tasks that must be completed inside living spaces is finishing window openings. However, to minimize this work, extension jamb liners can be prefabricated out of suitable material (finish grade plywood or MDF) and installed from inside once panels are installed. These jamb-liners can even be cased ahead of time, though it's likely that some adjustment will be necessary in the field.

11. COMMISSIONING, MEASUREMENT AND VERIFICATION

11.1 Monitoring IAQ impacts, hygrothermal performance and energy use

Project monitoring is crucial to ensure that project performance targets are met, regardless of whether it is a requirement to prove compliance with certain energy targets/programs. There are different intentions for a measurement and verification (M&V) program and the monitoring plan's level of detail should be adjusted accordingly. It is recommended that detailed monitoring is conducted for the first generation of PEER projects to build confidence in design assumptions, long-term performance, and to verify that the retrofit buildings perform as designed. Ideally, sensors can be installed well ahead of construction to collect a full year's worth of data prior to the retrofit. This will help characterize the pre-retrofit performance of the building and will allow for a more refined before and after comparison. CanmetENERGY is currently developing a M&V protocol for PEER and other deep retrofit projects. Project teams are encouraged to get in touch for more information.

11.1.1 Indoor environmental quality (IEQ) and thermal comfort monitoring

IEQ includes indoor air quality (IAQ) and thermal comfort metrics. These should be monitored pre and post retrofit. Basic metrics will include in-suite CO2, temperature, relative humidity (RH), and radon. Detailed IAQ monitoring may also include volatile organic compounds (VOCs), particulate levels, and pressure.

11.1.2 Hygrothermal monitoring

Hygrothermal monitoring can be carried out to understand the durability and performance of the existing and new enclosure assemblies following the retrofit. A monitoring plan will typically include installing sensors throughout the building to collect data related to ambient conditions within cavities as well as the conditions on the surfaces of moisture sensitive materials. Local weather data and interior conditions are also important for boundary conditions. This dataset may include temperature, relative humidity, moisture content in organic materials and differential pressure measurements. The data collected can be used to assess the risk of moisture related deterioration in the building enclosure.

11.1.3 Energy monitoring

Energy monitoring can be performed to assess whether energy targets are being achieved over multiple years post-retrofit.

At its most basic, energy monitoring can include collecting utility bills. Detailed energy monitoring can be load-by-load or circuit-by-circuit. Local weather data will also be needed to normalize modelled energy use to compare to monitored energy consumption.

11.2 Airtightness testing and enclosure commissioning

11.2.1 Airtightness testing

Airtightness testing requirements will vary depending on the overall project energy targets as well as the local building code requirements (if applicable). However, it is assumed that the airtightness requirements resulting from the project's energy target will exceed any local building code requirements. Typically, testing of the whole building at once is required; however, alternative approaches may be more applicable for buildings with many separate interior volumes and buildings with phased occupancy.

To meet airtightness testing requirements in Canada for Part 9 buildings, airtightness testing methodology should comply with standard CGSB 149.10-2019 Determination of the airtightness of building envelopes by the fan depressurization method. In some cases, ASTM E779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization or USACE Version 3 Air Leakage Test Protocol for Building Envelopes may be appropriate alternative test methods.

To meet the requirements for Passive House Certification the testing methodology will comply with standard ASTM E1827 or CGSB 149.10-2019, with the air volume calculated per the relevant standard requirements.

For more information regarding airtightness testing requirements, please refer to the relevant code or program and the applicable testing requirements.

11.2.2 Enclosure commissioning

Building Enclosure Commissioning (BECx) is a quality-oriented process deployed through all phases of a project from design development to post-occupancy and operations. The BECx process strives to define, verify, document, and update expectations related to enclosure performance through each iteration of a project.

Over the course of a project, the project team must work together with other stakeholders with the common goal of completing a building enclosure that achieves complex and diverse performance requirements. These may include but are not limited to aesthetics, structural load limits, thermal resistance, air and water control, energy performance, constructability, durability, resilience, and maintainability.

Success of the BECx process ultimately depends on a carefully considered and thoroughly executed plan. It is recommended that this plan is implemented early in the design process and followed through into operations (typically ten months post occupancy).

PEER projects will introduce non-conventional quality assurance and quality control (QA/QC) checkpoints, these may include:

1. Inspection of windows and air barrier/water resistive barrier prior to cladding being installed during prefabrication process;

2. Inspection and blower door testing (airtightness testing) once air barrier connections/transitions are completed but prior to covering with cladding on-site;

3. Inspection and another blower door test (if applicable) after all mechanical penetrations are completed.

It is recommended that the building enclosure commissioning plan is developed and implemented by a professional project team member who is experienced in project commissioning. Typically, this service is provided by a building enclosure consultant/engineer.

12. COST

As part of a scalable, industrialized retrofit process, PEER aims to reduce cost and accelerate uptake of deep retrofits through three mechanisms:

1. **Reducing costs of professional design services:** Traditional deep energy retrofits are custom-designed solutions. Each retrofit depends on the expertise of design professionals such as architects, structural engineers, building scientists and energy advisors. The service fees charged by each of these professionals increases costs significantly and cannot be transferred to a future project. By shifting retrofits from a project-driven business to a product-driven business, standardized solutions can be rapidly applied to many houses and buildings with minimal design intervention.

2. **Exploiting advances in digitalization, off-site construction, and automated fabrication:** Today, Canada's building industry is transforming from traditional site-built practices to factory-built approaches that embrace digitalization, off-site construction, and robotic fabrication. Industry analysts have concluded that this transformation is essential to unlocking the same gains in efficiency, productivity, quality, and innovation that have benefitted the automotive industry. PEER will accelerate this transformation by using the same technology to retrofit—both increasing the demand for prefab building components and enabling renovation projects to benefit from the cost savings associated with automation.

3. **Consolidating and strengthening supply chains for renovation products and services:** Industrialization will strengthen demand for common renovations—thereby encouraging larger suppliers to offer standardized products and services. This transition will increase the availability of deep retrofit solutions, while also reducing the costs.

12.1 Cost reductions in Europe

Evidence from other jurisdictions shows that this approach works. In the Netherlands, Energiesprong reported a 50% reduction between initial prototypes (CAD$187K) and subsequent units constructed at scale (CAD$94K).

12.2 Total cost of building ownership

Evaluating the business case of a deep retrofit based on energy savings alone provides an incomplete picture. A better approach is to assess maintenance, insurance, property and carbon taxes and other costs affected by the retrofit over the long-term. Total Cost of Building Ownership (TCBO) is a methodology that provides a more complete picture of the net costs of building ownership and operation over the useful life of the building. TCBO involves comparing the energy use, remaining life, and replacement cost of major systems of maintaining an existing building against a deep retrofit scenario.

The OCH project undertook a TCBO using the SEEFAR methodology. The TCBO of an existing (business as usual) building (four townhouse units) and compared it to the same building retrofit with high performance, panelized envelope, all heat-pump space conditioning and water heating, and a PV array to achieve net-zero. The objective was to provide evidence to the building owners and lenders of the long-term financial value of such an investment and to provide a method for accounting for this in their financial planning and appraisal practices.

OCH's Capital Planning Branch was consulted to estimate the required capital for four scenarios:

a. Base Case: To maintain the existing building in its current condition and performance level (replacing components (i.e., shingles, windows, furnaces) with equivalent systems as needed);

b. A net-zero ready PEER retrofit with all-electric heat pump systems;

c. Scenario B with sufficient solar to achieve net-zero energy;

d. Scenario C with a 30% cost reduction (to represent savings by retrofitting at scale);

Assumptions:

- Annual cost of borrowing of 0.84%.
- Annual electricity escalation rate of 4%.
- Annual natural gas escalation rate of 2%.
- Carbon levy of $20/tonne escalating at 4% annually.

Table 12-1: Deployed capital over 60 years

Deployed Capital	A	B	C	D
	Existing Building	Fully-electrified Net-Zero Ready (NZr) Retrofit	Net-Zero PEER Retrofit	Net-Zero PEER Retrofit and 30% Cost Reduction
Over 60 Years	CAD$632K	CAD$1,022K	CAD$1,022K	CAD$742K
Incremental Increase in Capital	**Base Cost**	CAD$390K	CAD$490K	CAD$110K
Percentage Capital Increase	**Base Cost**	62%	78%	17%

Table 12-2: Annual energy consumptions and GHG emissions

Annual Energy Consumption and GHG Emissions	A	B	C	D
	Existing Building	Fully-electrified Net-Zero Ready (NZr) Retrofit	Net-Zero PEER Retrofit	Net-Zero PEER Retrofit and 30% Cost Reduction
GHG emissions (kg)	18,000	1,000	–	–
Electricity (kWh)	29,763	37,292	37,292	37,292
Solar PV generated (kWh)	–	–	(37,292)	(37,292)
Natural Gas (m^3)	8,884	–	–	–
Total Annual Energy Consumption (ekWh)	121,567	37,292	–	–
Total Annual Energy Consumption (GJ)	438	134	–	–
EUI ($kWh/m^2/year$)	296	91	–	–

The results of this analysis suggested that even at the estimated costs for a one-off demonstration project, there was a compelling business case and return on investment. Although Scenario B promised to reduce energy use by 70%, little energy cost savings were expected. This is because the project involved fuel switching all thermal demands to a higher cost energy (from natural gas to electricity).

However, with the inclusion of renewables (scenario C), the energy usage costs are effectively eliminated (grid connection fees remain). This analysis did not attempt to quantify additional cost savings from improved occupant health, comfort, and resilience to climate risks.

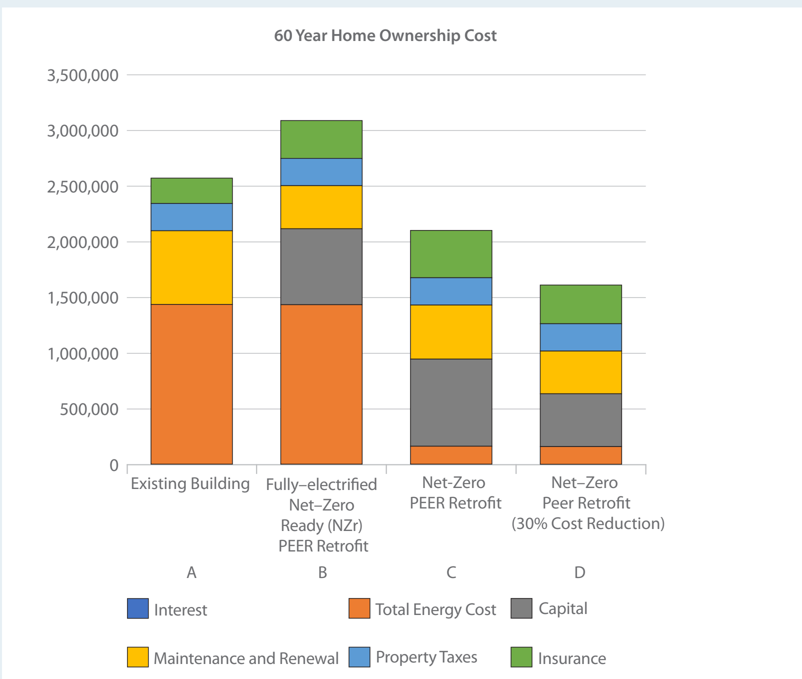


Figure 12-1: 60-year Total Cost of Building Ownership analysis for 4 scenarios: A. Maintain existing building; B. All-electric, net-zero ready PEER retrofit; C. All-electric, net-zero PEER retrofit; and D. Scenario C with a 30% cost reduction.

12.3 Panel costs

A comprehensive costing analysis of different panel types has not been performed. Material and labour costs will fluctuate and vary by market.

In 2017, CanmetENERGY completed a small proof-of-concept PEER pilot which involved retrofitting an existing building with two panel types, side-by-side. Cost data from that project is provided in Figure 12-2, below.

In the 2020 Ottawa Community Housing project, the above and below grade walls were retrofitted for approximately CAD\$700/m^2 (CAD\$65/ft^2) including materials and labour.

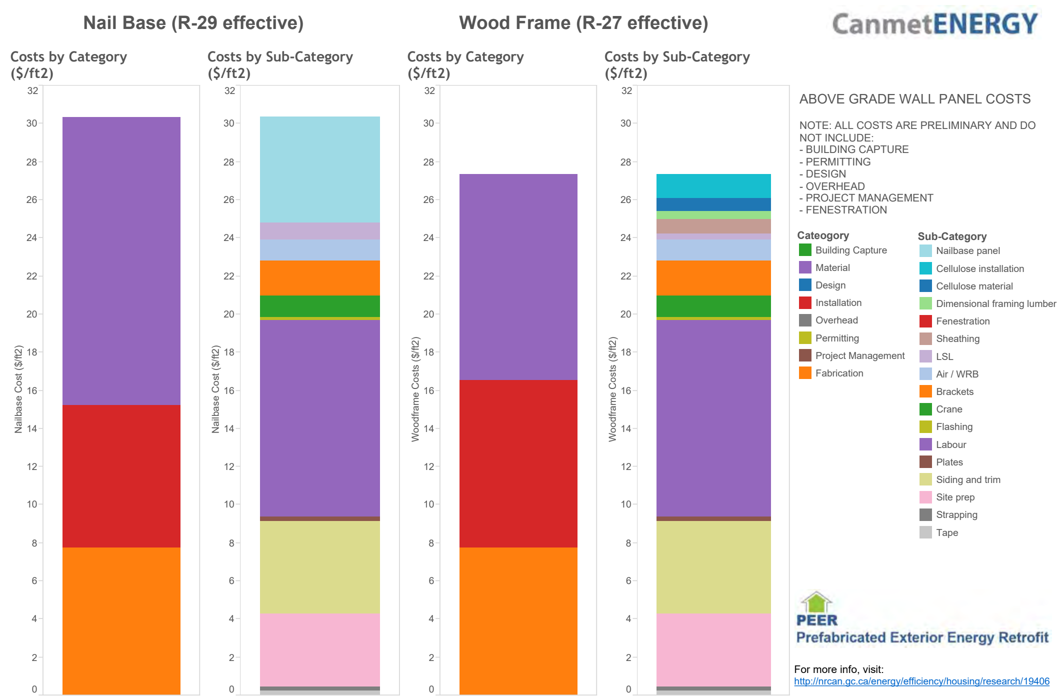


Figure 12-2: 2017 cost breakdown for an R-29 Nailbase panel; and an R-27 Wood-frame Stand-Off Panel.

12.4 Market Size

Canada's subsidized housing stock consists of an estimated 550,000 to 650,000 units [30]. Although the official national estimate is just under 550,000, the real number of subsidized units (including those that have recently come off agreements) is likely closer to 650,000, according to CMHC.

13. CONCLUSIONS AND NEXT STEPS

The PEER Project was a six year R&D project, funded by the Program of Energy Research and Development. Under the project, a technical approach to using prefabricated panels to retrofit Canadian houses and small buildings under Part-9 of the National Building Code was developed. Five panel prototypes were developed and three of these have been field tested to date. These prototypes were based on panels that already exist in the Canadian market for new construction. Fabrication processes were limited to manual operations that would be familiar to residential construction trades in Canada. The PEER process enables a scalable approach to rapid enclosure retrofit while occupants remain in place. This guide is the ultimate deliverable of the project.

In the next research cycle CanmetENERGY intends to adapt the process to include additional building typologies (including Part-3 multi-unit residential buildings (MURBs)) and additional enclosure assemblies (including retrofits of foundations and roofs). Assemblies using low-carbon and carbon-storing materials will be developed and tested. Advances in digital building capture, design, automation and off-site construction will be investigated to determine their suitability and potential for further increasing labour productivity and scaling the approach.

The Government of Canada is investing $35.5M over five years, starting in 2022–23, for Natural Resources Canada (NRCan) to implement a Greener Neighbourhoods Pilot Program (GNPP) that aims to begin building a pipeline of aggregated deep retrofit projects in up to six community housing neighbourhoods in Canada. This scale of project and similarity of buildings can leverage new retrofit approaches such as the use of prefabricated exterior panels to reduce on-site labour time and overall project costs, while reducing the energy use intensity and emissions from each retrofitted building.

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APPENDIX A: PEER PANEL DESIGN BRIEFS

A.1 PEER Wall — Structurally Insulated Panel Wall System

A.2 PEER Wall — 2x4 Framed Panel Wall System

A.3 PEER Wall — Nailbase Panel Wall System

A.4 PEER Wall — I-Joist Framed Panel Wall System

A.5 PEER Wall — Exterior Insulated Finished System Panel

Natural Resources Canada   Ressources naturelles Canada

A.1 PEER Wall — Structurally Insulated Panel Wall System

A SIP wall for prefabricated exterior energy retrofit using advanced materials and techniques.

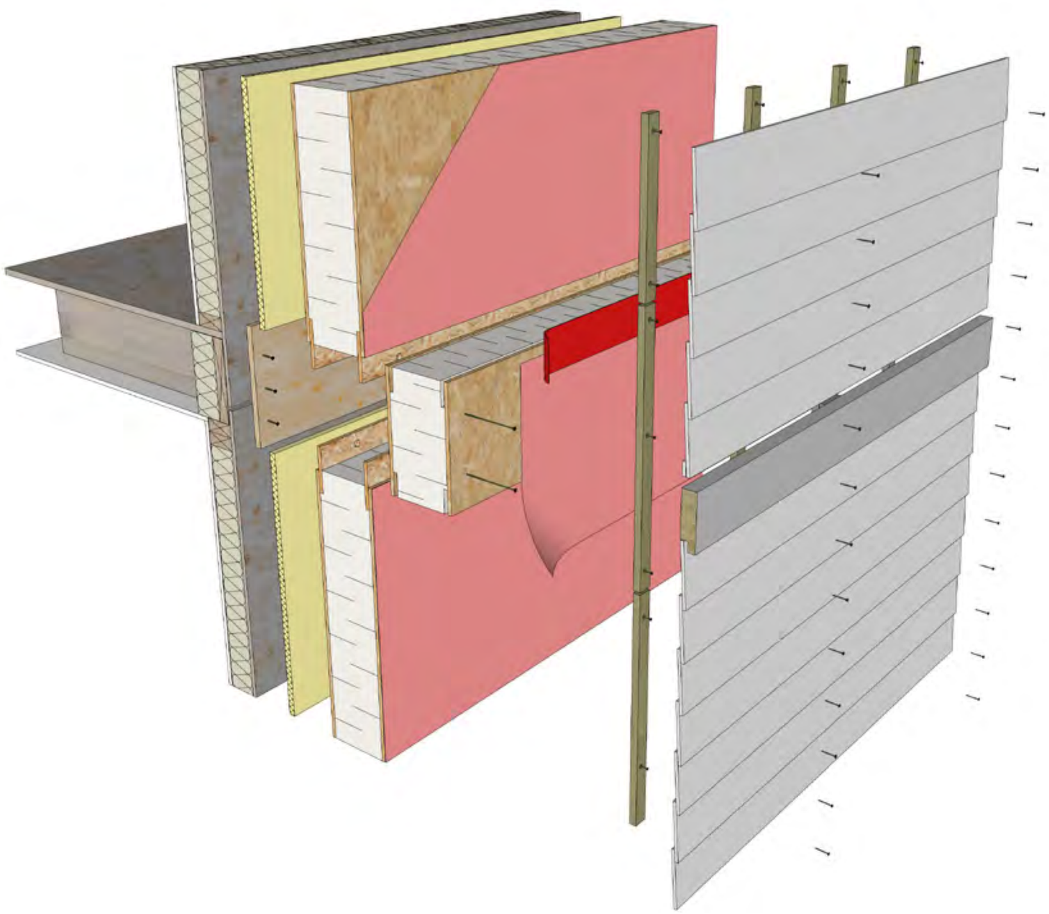


Figure 1   Exploded view of partial retrofit panel components at floor line transition

Developed by Natural Resources Canada's Prefabricated Exterior Energy Retrofit (PEER) team

CanmetENERGY

Canada

A.1 PEER Wall — Generation 2 SIP Enclosure Assembly Overview

The following is a description of the retrofit panel layers installed on the exterior of the existing house. See also the Typical Construction Details on page 5.

Exterior

- Cladding
- Borate-treated strapping + air cavity
- Self-adhered vapour permeable membrane (air barrier and water resistive barrer)
- SIP: Exterior OSB sheathing, EPS insulation, interior OSB sheathing, layers glued together
- Compressible mineral fibre gap fill insulation
- Existing assembly (not shown)

Interior

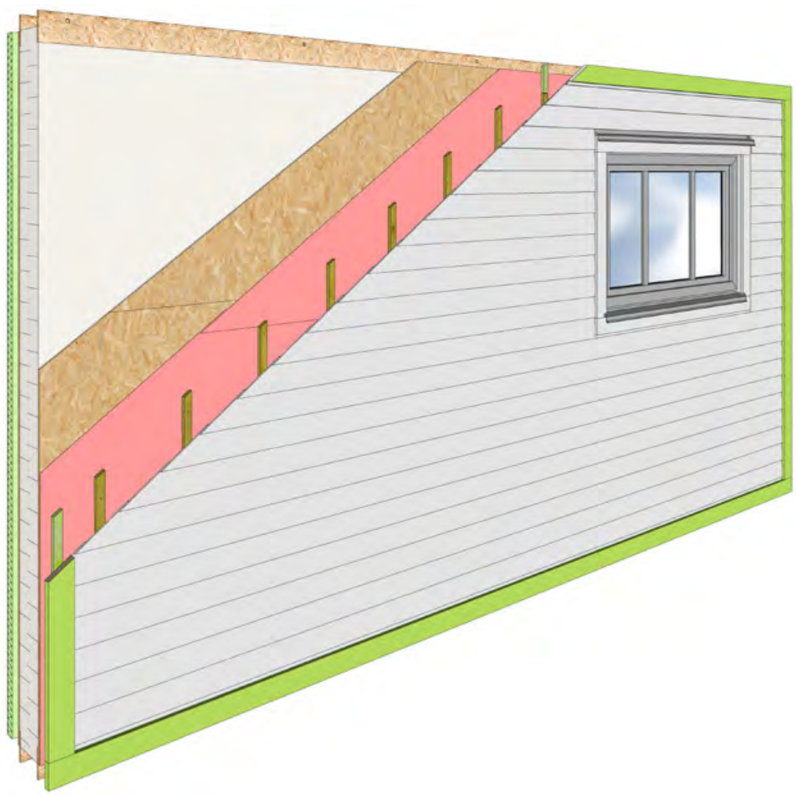


Figure 2 Retrofit SIP wall panel overview (green highlights indicate site-applied perimeter joint/tie-in components)

Retrofit Description

- Panels can be installed over the existing wall either with the cladding removed or left in place, and the existing windows and interior trim removed. A mineral fibre insulation layer is installed over the existing assembly to provide for in-out tolerance of the panel installation while baffling the small space between the panel and the existing wall.
- SIPs are positioned and fastened into a continuous insulated box beam supported by intermittent foundation brackets at the base of the above grade wall, a rim panel at the following storey floor line, and to a plywood plumb shim at the roof line.
- The air barrier/weather resistive barrier (AB/WRB, denoted with red callouts in the details) is a factory-installed self-adhered membrane at the exterior OSB sheathing. Joints are face sealed with transition membrane and compatible pressure sensitive acrylic tape.
- New windows (and their trim/closures) can be pre-installed into the panels at the factory or site installed after panel placement to accommodate for tolerances. Window AB/WRB transition/ rough-opening membranes are factory installed on the SIP.
- The drained and ventilated rainscreen cladding comes pre-installed except at panel joints and at window interfaces (if site installed).
- Closure cladding, flashing, and trim is installed as required at panel joints and windows.

Potential Benefits of a Structural Insulated Panel Retrofit

- All work (except interior window trim) is done from the exterior leaving the home livable during construction.
- Site installation work is limited, reducing installation times and disruption to residents.
- Eliminates on-site framing and using manufactured panels simplifies installation.
- Insulation thickness can be varied to accommodate energy performance goals and lot-line setbacks.
- Provides a layer of continuous insulation reducing thermal bridging through framing.
- Increases air tightness, reduces drafts and noise, and lowers energy costs.
- Reduces potential for moisture ingress with careful detailing.
- Provides opportunity for seismic upgrades to meet regional requirements.
- The structural rigidity provided by SIPs allow for larger panels and provide some load bearing capacity for exterior window installation.
- Allows for quality control of the air barrier system at the factory before it is covered with cladding.
- Allows for quality assurance of the air barrier system transitions on site prior to installing closure cladding.
- Use of full SIPs enables larger panels with more load bearing capacity compared to nailbase panels.
- CCMC approved SIP systems available which may facilitate permitting.

Key Considerations

Air sealing: The air barrier (AB) is provided by the membrane at the exterior side of the SIP. Flexible membrane flashings around panel joints, windows, doors, other penetrations and transitions complete the AB. Sealing at the top plate and foundation where the new wall connects to the existing house is also required. The openings around electrical, mechanical, and other penetrations are sealed throughout the construction process. These are critical details to ensure an airtight barrier.

Connection to existing structure: This retrofit uses structural brackets and a continuous box beam at the base of the above grade wall to support the first floor SIP at its base. A rim panel at the floor line of the following storey is attached to the existing structure and provides support for the top of the first floor SIP and bottom of the second storey SIP. Long screws through the SIP into a plywood plumb shim and existing building framing produces a self-supporting sandwich at the top of the second storey SIP. Windows moved to the exterior provide for easy sealing to the AB/WRB.

Water control: The membrane on the exterior sheathing of the SIP acts as the water resistive barrier (WRB). Strapping is factory installed over the WRB and fastened to wall framing to provide a rainscreen cavity behind the cladding.

Cladding: This system must be easily transported and therefore only allows for lighter cladding materials. Materials such as cement board or pre-finished wood are factory installed directly to the strapping. Site install of some cladding around panel joints and windows may be required.

Durability: The SIP panels will have a reduced drying potential dependant on the thickness of the EPS insulation. Applications should be modelled to assess risk.

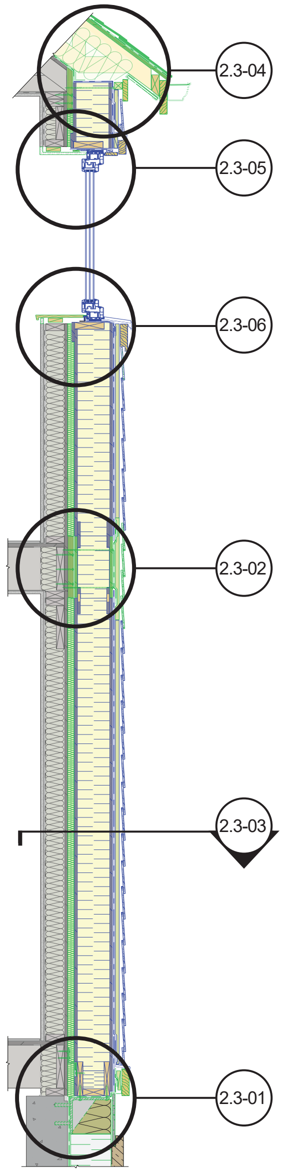


Figure 3 House section detail wayfinder.

Typical Construction Details

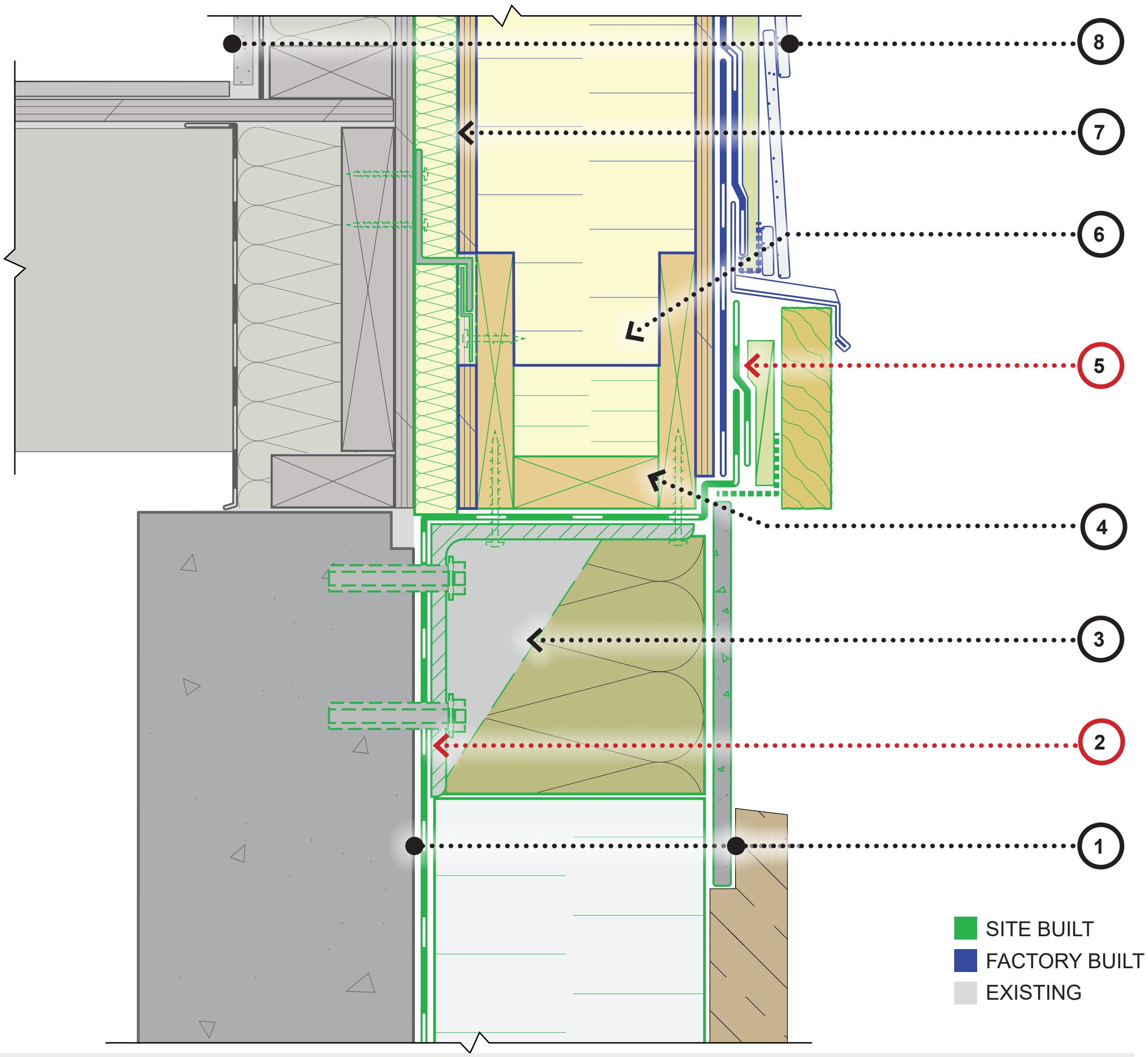
The sample details shown in the following pages are intended to illustrate typical transition approaches both for air barrier and panel/insulation continuity. Note that these are example details, and project-specific details should always be developed to account for the unique conditions of each project.

The annotations and legend in each sample detail contains red “AB” and "AB/WRB" icons to indicate the various air barrier and where applicable water resistive barrier components are present.

Each detail also include a colour legend as follows for the grey, green, and blue components shown:

- SITE BUILT
- FACTORY BUILT
- EXISTING

List of Details

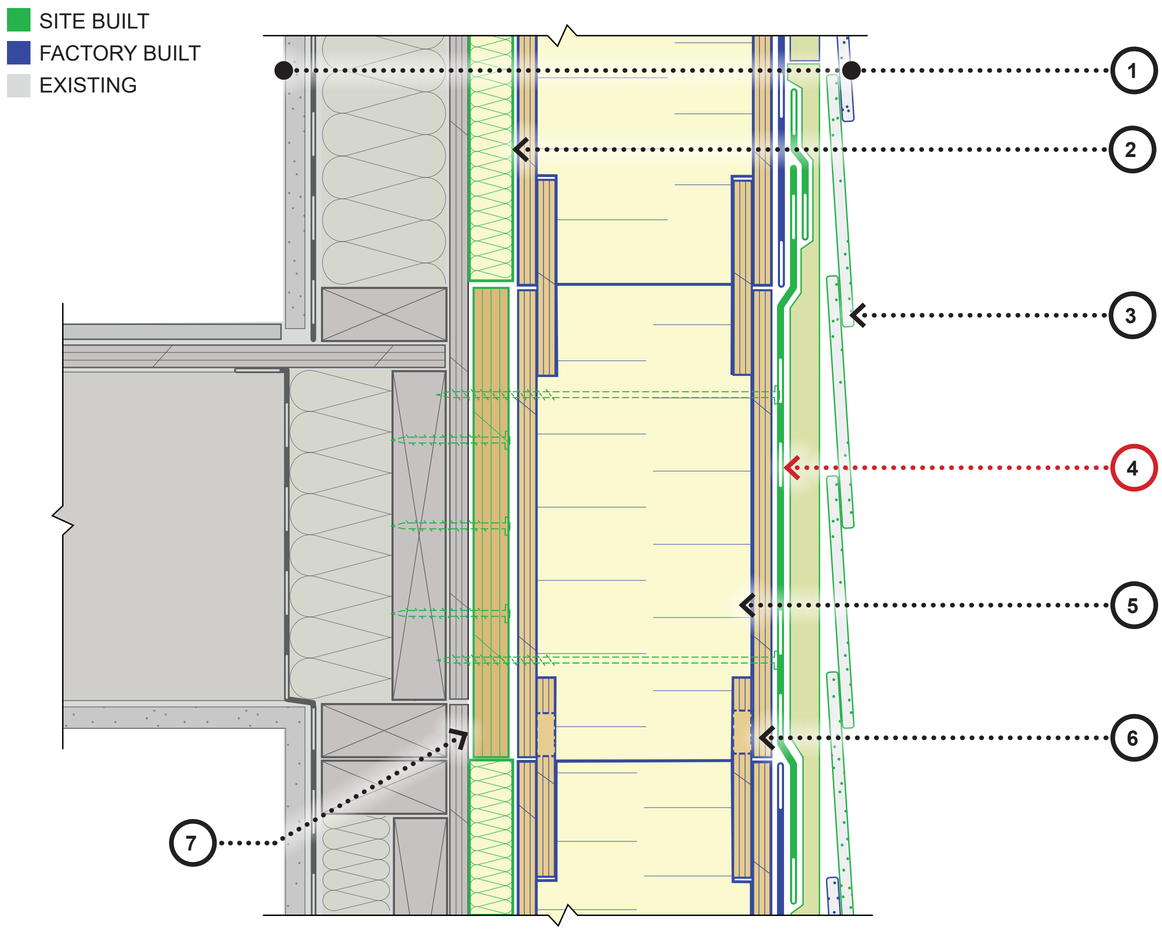


LEGEND

1. Below-grade wall assembly:
   - Fiber cement board
   - EPS foam insulation
   - Self-adhered transition membrane (AB/WRB)
   - Existing assembly
2. Pre-strip transition membrane prior to foundation bracket install. (AB/WRB)
3. Intermittent foundation bracket surrounded with mineral wool insulation.
4. Site installed continuous insulated box beam fastened to existing structure with intermittent clips.
5. Transition membrane reverse lapped over factory installed VP membrane with leading edges sealed with high performance tape. (AB/WRB)
6. SIP panel positioned into site installed box beam.
7. Compressible mineral fibre gap fill insulation.
8. SIP Wall System 2.0.

Detail A.1–01 | Base of Wall at Foundation

PEER Wall A.1 — SIP 2.0

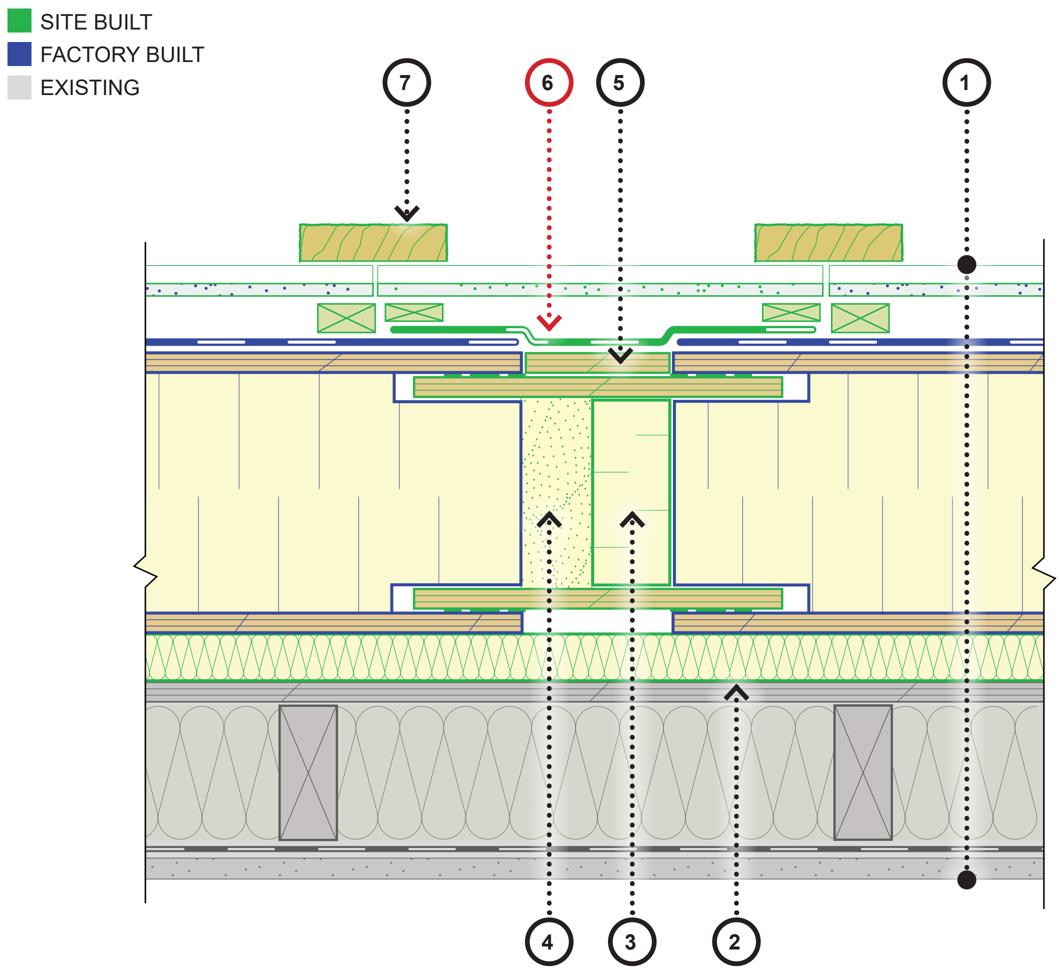


LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. Site applied cladding and strapping across joint.
4. Self-adhered VP transition membrane sealed over rim panel first floor membrane. Reverse lap at leading edge sealed with high performance tape. (AB/WRB)
5. Rim panel fastened and adhered to plywood plumb shim with construction adhesive.
6. Reinforced lifting hole in top of SIP splines.
7. Plywood plumb shim fastened to existing structure at floorline.

Detail A.1–02 | Horizontal Panel Joint

PEER Wall A.1 — SIP 2.0

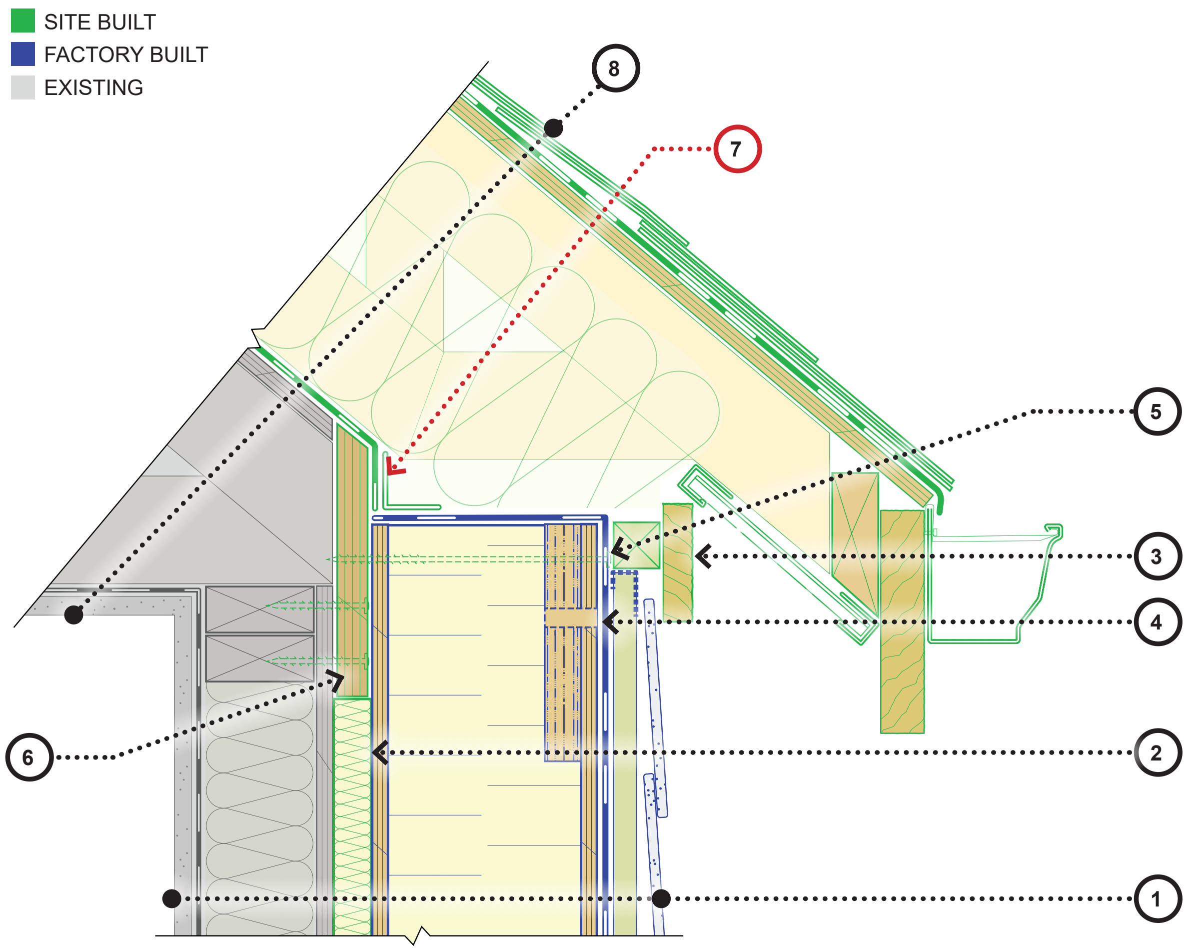


LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. EPS filler block.
4. Self-expanding foam joint sealant.
5. Front and rear splines glued in place.
6. Site installed self-adhered VP membrane over splines. (AB/WRB)
7. Site installed trim over vertical cladding joints.

Detail A.1–03 | Vertical Panel Joint

PEER Wall A.1 — SIP 2.0

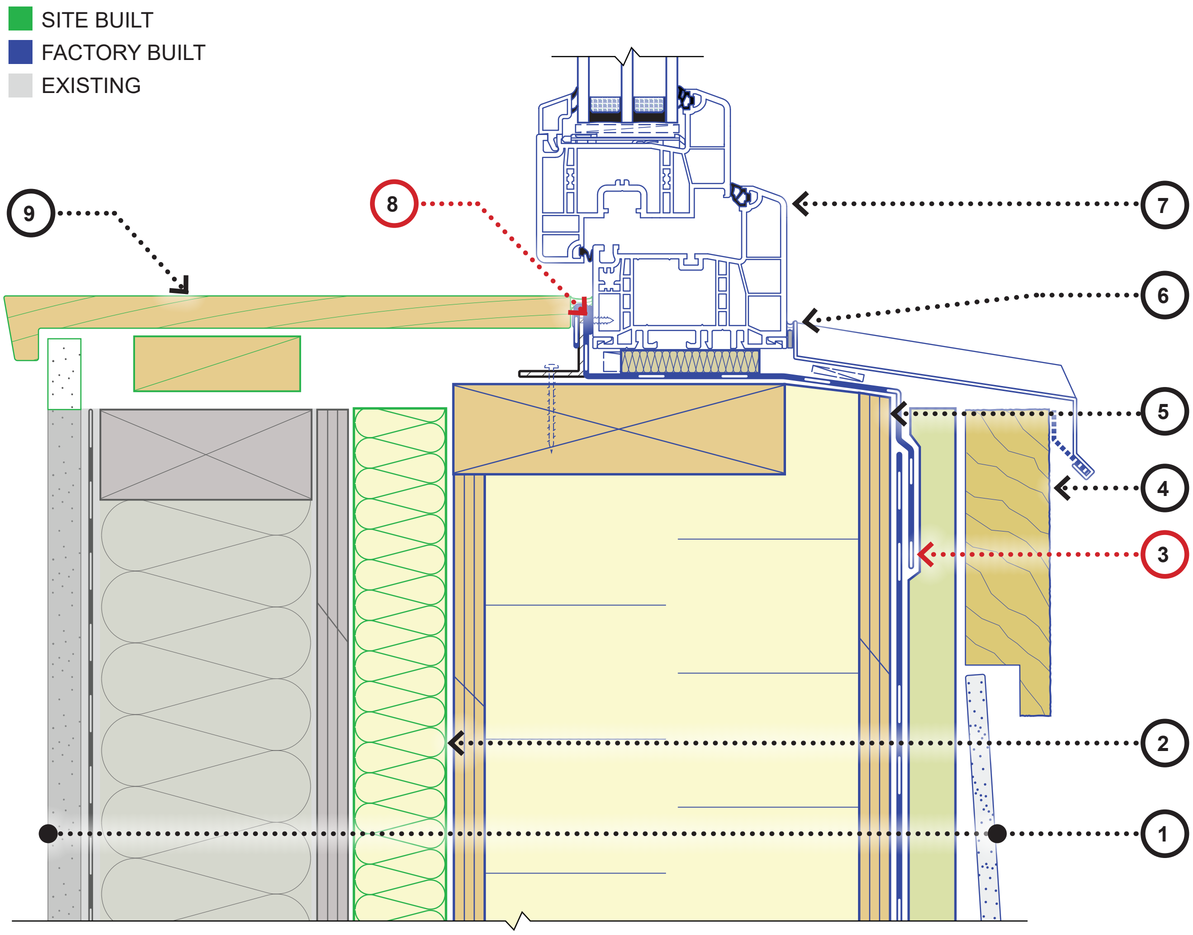


LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. Lifting holes through exterior sheathing and LSL beam.
4. Site-applied closure trim at top of wall.
5. Panel fastened to existing roof structure.
6. Plywood plumb shim fastened at cut back existing roof structure (chainsaw retrofit).
7. High performance tape sealed to factory installed self-adhered membrane and roof assembly membrane. (AB/WRB)
8. Chainsaw retrofit roof assembly.

Detail A.1–04 | Top of Wall

PEER Wall A.1 — SIP 2.0

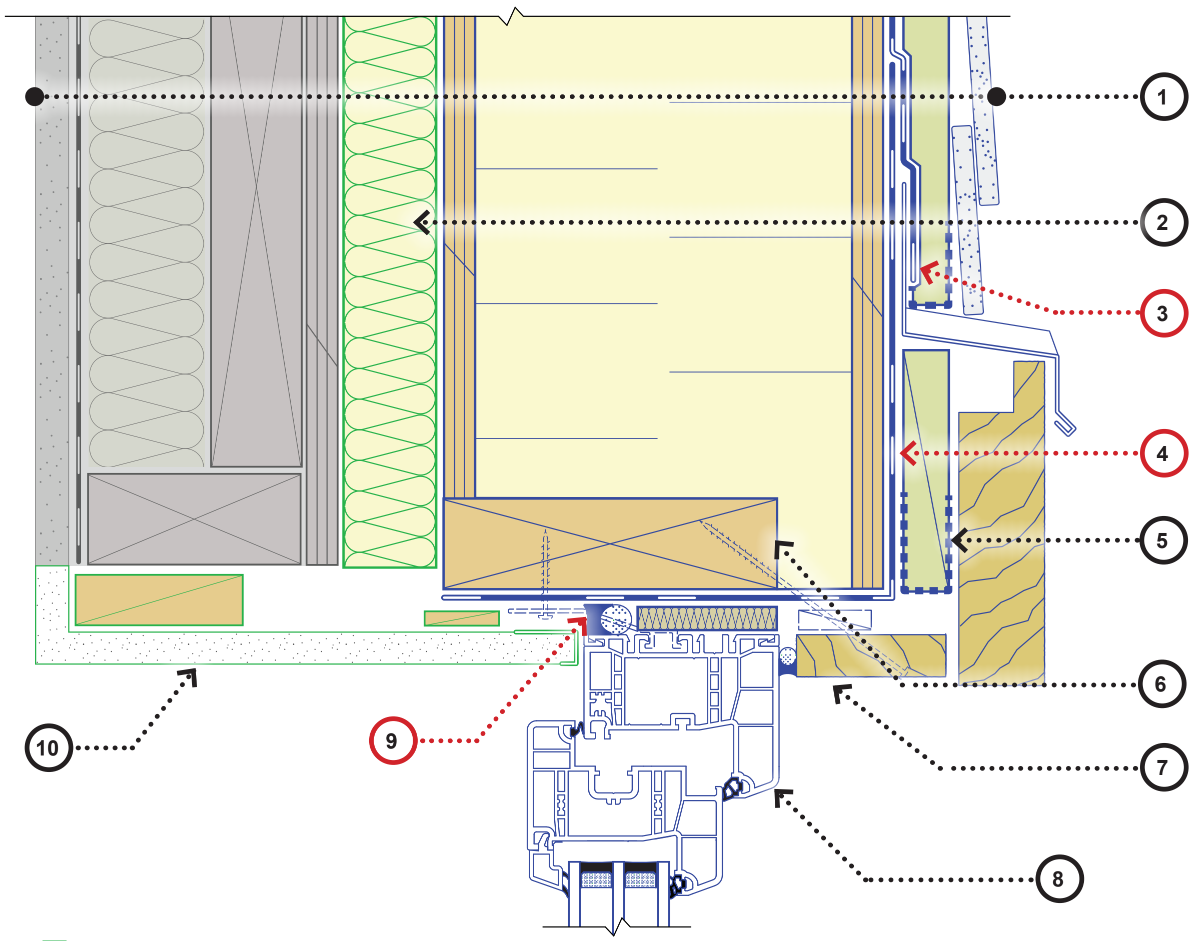


LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. Factory installed self-adhered sill membrane over sill angle and lapped onto field membrane. (AB/WRB)
4. Closure cladding and trim around window.
5. SIP insulation and exterior sheathing sloped at front edge. Intermittent shims to support sill flashing.
6. Window sill flashing.
7. New triple-glazed window secured in place with sill angle at sill.
8. Window set into continuous sealant over sill angle and secured with screws. (AB/WRB)
9. Interior window trim and closure sealant over sill angle as required.

Detail A.1–05 | Window Sill

PEER Wall A.1 — SIP 2.0



SITE BUILT
FACTORY BUILT
EXISTING

LEGEND

1. SIP Wall System 2.0.
2. Compressible mineral fibre gap fill insulation.
3. Site installed closure cladding and self-adhered membrane over head flashing and lapped over head flashing membrane. (AB/WRB)
4. VP head flashing membrane. (AB/WRB)
5. Factory installed window head prestrip and strapping.
6. 2x6 wood buck positioned at back of SIP panel.
7. Head trim toe nailed into 2x6 window buck.
8. New triple-glazed window secured in place with clips at head and jambs.
9. Continuous sealant installed between rough-opening and window head/jambs.
10. Interior gypsum.

Detail A.1–06 | Window Head

PEER Wall A.1 — SIP 2.0

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A.2 PEER Wall — 2x4 Framed Panel Wall System

Framed panel for prefabricated exterior energy retrofit using advanced materials and techniques.

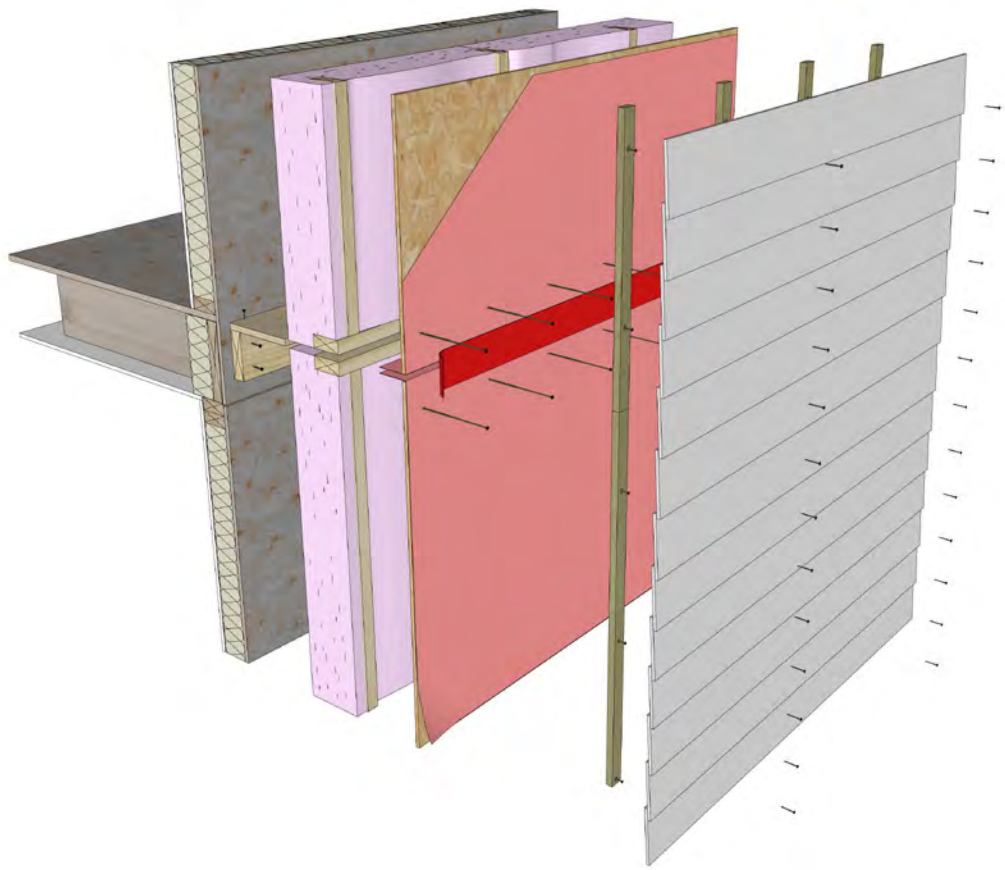

Figure 1 Exploded view of partial retrofit panel components at floor line transition

Developed by Natural Resources Canada's
Prefabricated Exterior Energy Retrofit (PEER) team

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A.2 PEER Wall — 2x4 Framed Panel Wall Assembly Overview

The following is a description of the retrofit panel layers installed on the exterior of the existing house. See also the Typical Construction Details on page 5.

Exterior

- Cladding
- Borate-treated strapping + air cavity
- Self-adhered vapour permeable membrane (air barrier and water resistive barrier)
- Wall sheathing
- 2x4 framing with site installed blown-in cellulose insulation
- Existing assembly (not shown)

Interior

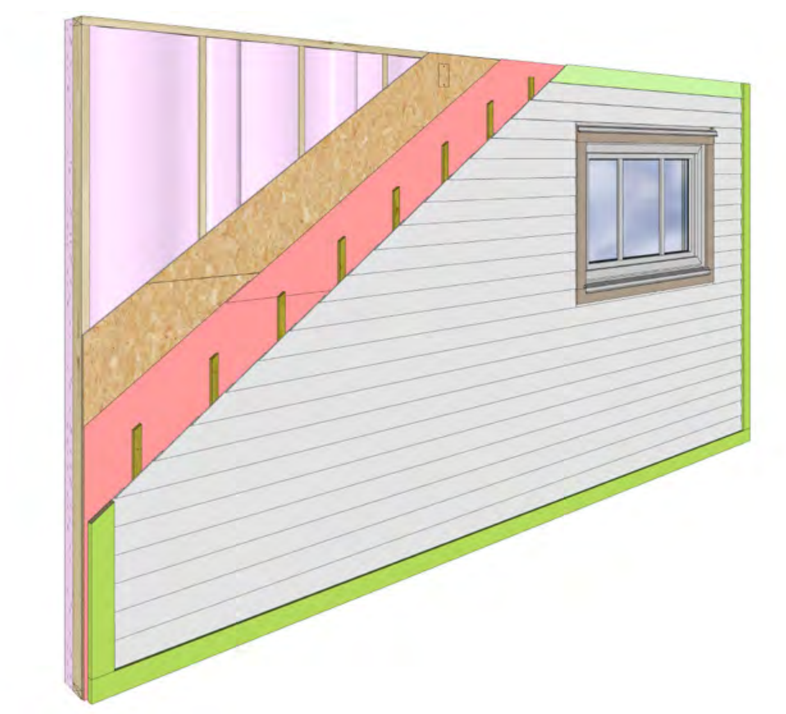


Figure 2 Retrofit 2x4 wall panel overview (green highlights indicate site-applied perimeter joint/tie-in components)

Retrofit Description

- Panels can be installed over the existing wall either with the cladding removed or left in place, and the existing windows and interior trim removed.
- 2x4 panels are fastened to a continuous insulated box beam supported by intermittent foundation brackets at the base of the above grade wall.
- The air barrier/weather resistive barrier (AB/WRB, denoted with red callouts in the details) is a factory-installed self-adhered membrane at the exterior sheathing, with various edges returning into joints and face sealed with compatible pressure sensitive acrylic tape.
- New windows (and their trim/closures) can be pre-installed into the panels at the factory or site installed after panel placement to accommodate for tolerances. Window AB/WRB transition/rough-opening membranes are factory installed on the panel.
- The drained and ventilated rainscreen cladding comes pre-installed except at panel joints and at window interfaces (if site installed).
- Intermittent insulation fill holes are included at the tops and bottoms of each panel stud cavity and below window openings so that fibrous insulation can be blown into the stud cavity and directly against the existing assembly.
- Insulation fill hole covers, AB/WRB membrane transition strips, closure cladding, flashing, and trim is installed as required at panel joints and windows.

Potential Benefits of a 2x4 Framed + Blown-in Insulation Retrofit

- All work (except interior window trim) is done from the exterior leaving the home livable during construction.
- Site installation work is limited, reducing installation times and disruption to residents.
- Eliminates on-site framing and uses manufactured panels to simplify installation.
- Insulation thickness can be varied to accommodate energy performance goals and lot-line setbacks.
- Provides a layer of continuous insulation reducing thermal bridging through framing.
- Increases air tightness, reduces drafts and noise, and lowers energy costs.
- Reduces potential for moisture ingress with careful detailing.
- Provides opportunity for seismic upgrades to meet regional requirements.
- The structural rigidity provided by sheathed panels allows for larger panels and load bearing capacity for exterior window installation.
- Allows for quality control of the air barrier system at the factory before it is covered with cladding.
- Allows for quality assurance of the air barrier system transitions on site prior to installing closure cladding.

Key Considerations

Air sealing: The air barrier (AB) is provided by the self-adhered membrane at the exterior side of the panel. Flexible membrane flashings around panel joints, windows, doors, and other penetrations and transitions complete the AB. Sealing at the top plate and base-of-wall where the new wall connects to the existing house is also required. Openings around electrical, mechanical, and other service penetrations are sealed throughout the construction process. These are critical details to ensure an airtight barrier.

Connection to existing structure: This retrofit uses structural brackets and a continuous box beam at the base of the above grade wall to support the first floor panel at its base. A continuous plywood tie-in plate at the floor line of the following storey is attached to the existing structure and provides lateral support for the top of the first storey panel and bottom of the second storey panel. Windows moved to the exterior provide for easy sealing to the AB/WRB.

Water control: The membrane on the exterior sheathing acts as the water resistive barrier (WRB). Vertical strapping is factory installed over the WRB to provide a rainscreen cavity behind the cladding.

Cladding: This system must be easily transported and therefore only allows for lighter cladding materials. Materials such as cement board or pre-finished wood are factory installed directly to the strapping. Site installation of some cladding around panel joints and windows may be required.

Insulating: While this retrofit makes very efficient use of materials, careful attention is required to ensure that all cavities are fully filled with fibrous insulation to their target density. Pre-installing cladding limits access points for site-installation of insulation and also makes QA/QC by thermography challenging. Uninsulated voids can result in convective air flows and condensation risk on the back of the sheathing.

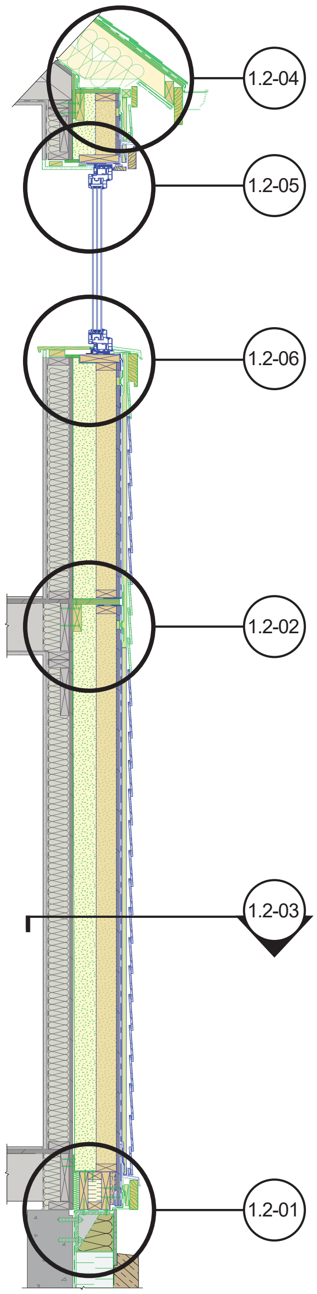


Figure 3 House section detail wayfinder.

Typical Construction Details

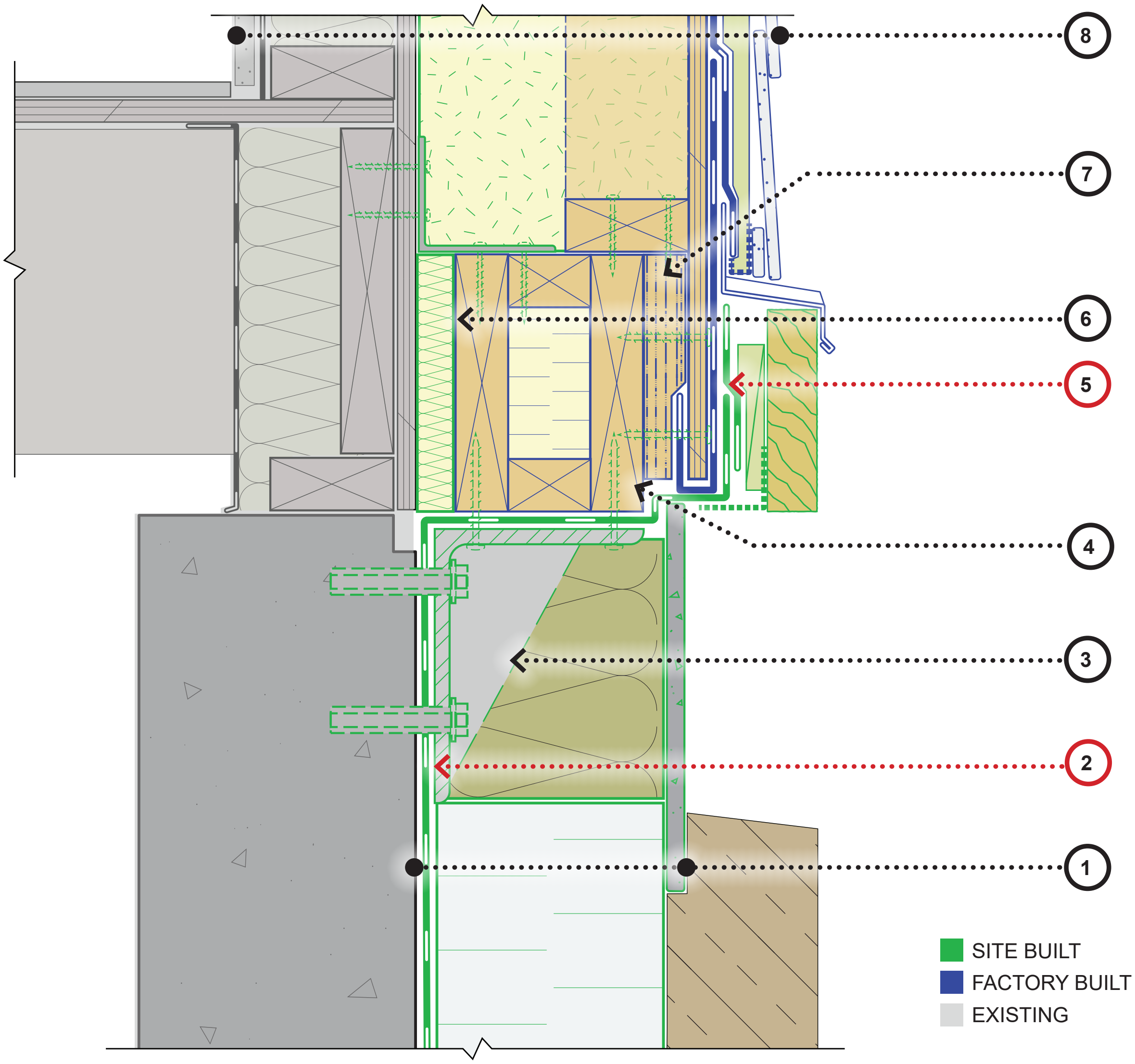
The sample details shown in the following pages are intended to illustrate typical transition approaches both for air barrier and panel/insulation continuity. Note that these are example details, and project-specific details should always be developed to account for the unique conditions of each project.

The annotations and legend in each sample detail contains red “AB” and "AB/WRB" icons to indicate the various air barrier and where applicable water resistive barrier components are present.

Each detail also include a colour legend as follows for the grey, green, and blue components shown:

- SITE BUILT
- FACTORY BUILT
- EXISTING

List of Details



LEGEND

1. Below-grade wall assembly:
- Fiber cement board
- EPS foam insulation
- Self-adhered transition membrane (AB/WRB)
- Existing assembly

2. Pre-strip transition membrane prior to foundation bracket install. (AB/WRB)

3. Intermittent foundation bracket surrounded with mineral wool insulation.

4. Continuous insulated box beam fastened to existing structure with intermittent deck ties.

5. Site- applied transition membrane reverse lapped over factory installed VP membrane with leading edges sealed with high performance tape. (AB/WRB)

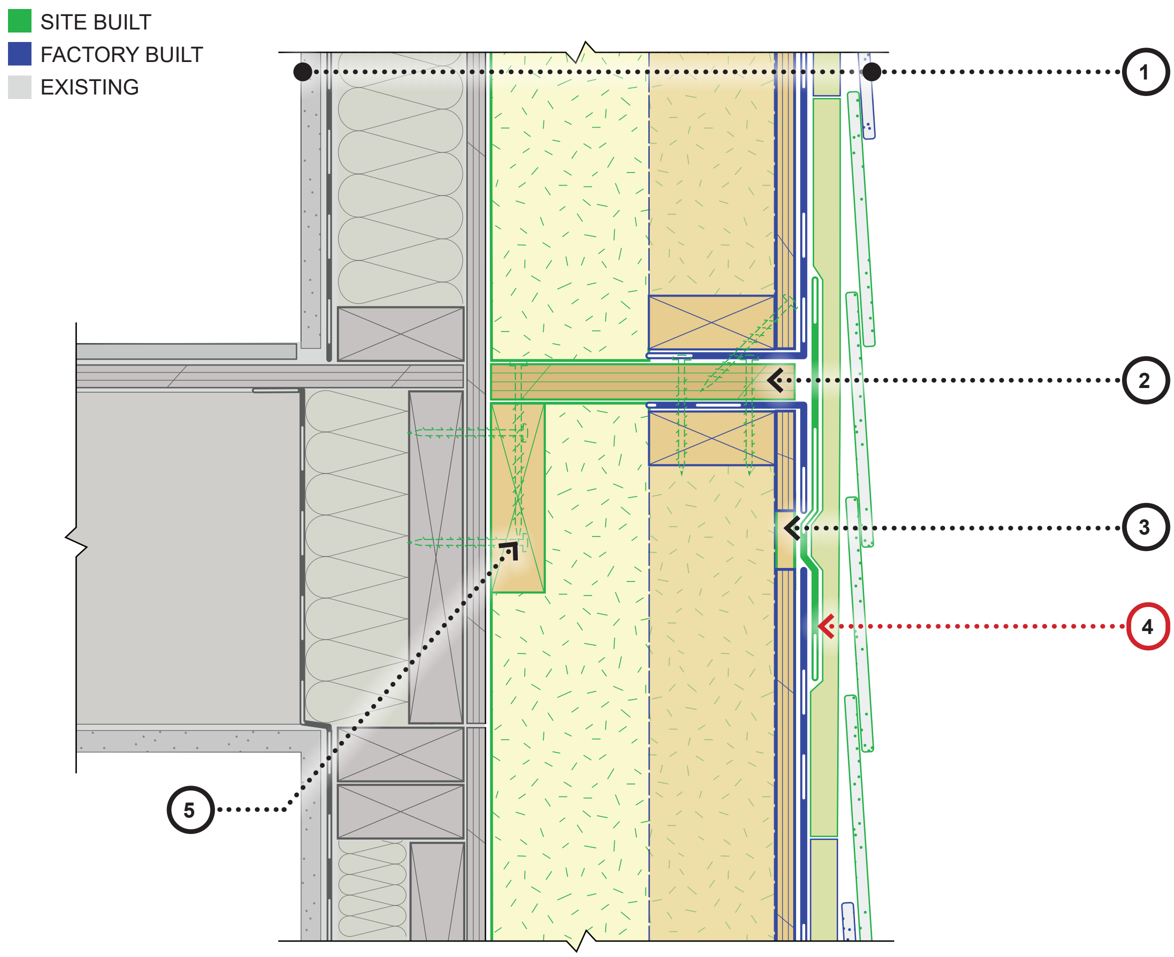
6. Compressible mineral fibre gap fill insulation.

7. LSL plate at base of 2x4 frame fastened to box beam.

8. 2x4 Framed Assembly.

Detail A.2–01 | Base of Wall at Foundation

PEER Wall A.2 — 2x4 Framed

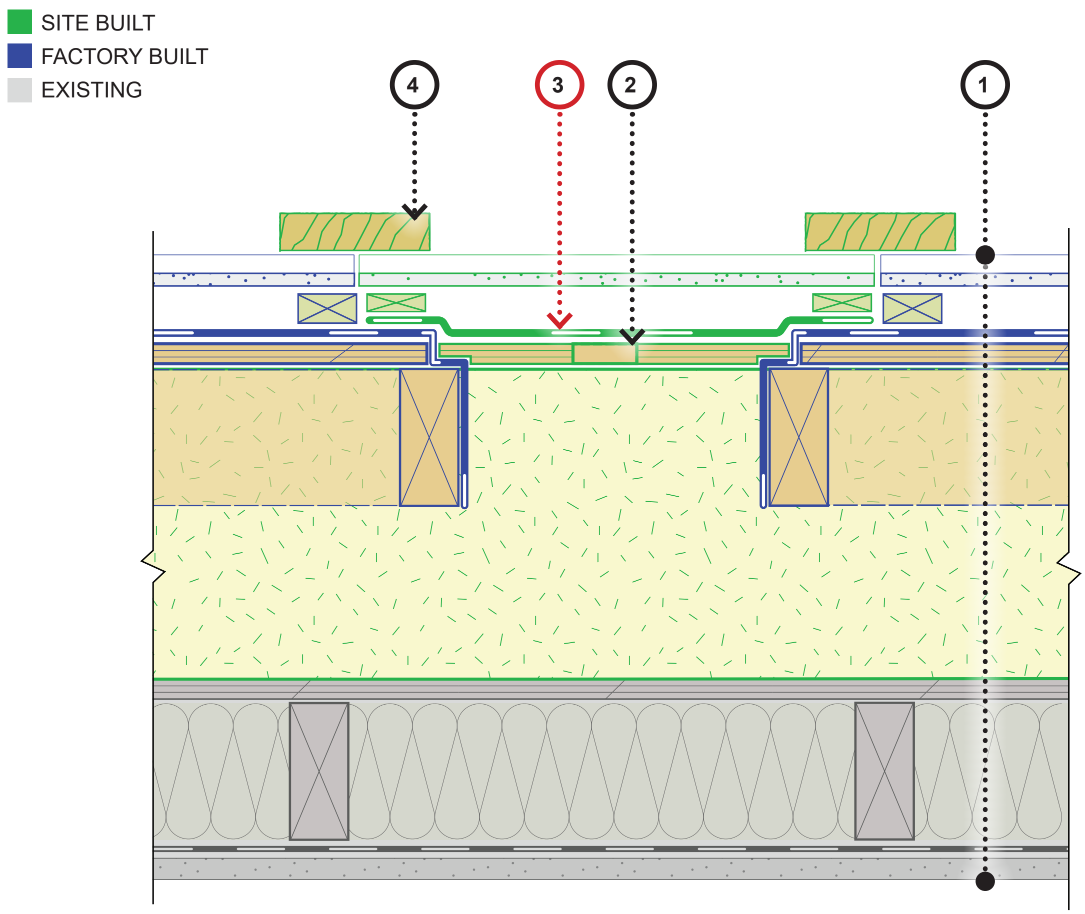


LEGEND

1. 2x4 Framed Assembly.
2. Wood panel fastened to plywod plumb shim.
3. Intermittent lifting hole and insulation fill slot. Slot to be sealed after installation of insulation.
4. Second floor self-adhered VP membrane sealed to first floor membrane and over lifting hole/insulation fill slot with high performance tape. (AB/WRB)
5. Wood blocking fastened to plywood plumb shim to support panel.

Detail A.2–02 | Horizontal Panel Joint

PEER Wall A.2 — 2x4 Framed

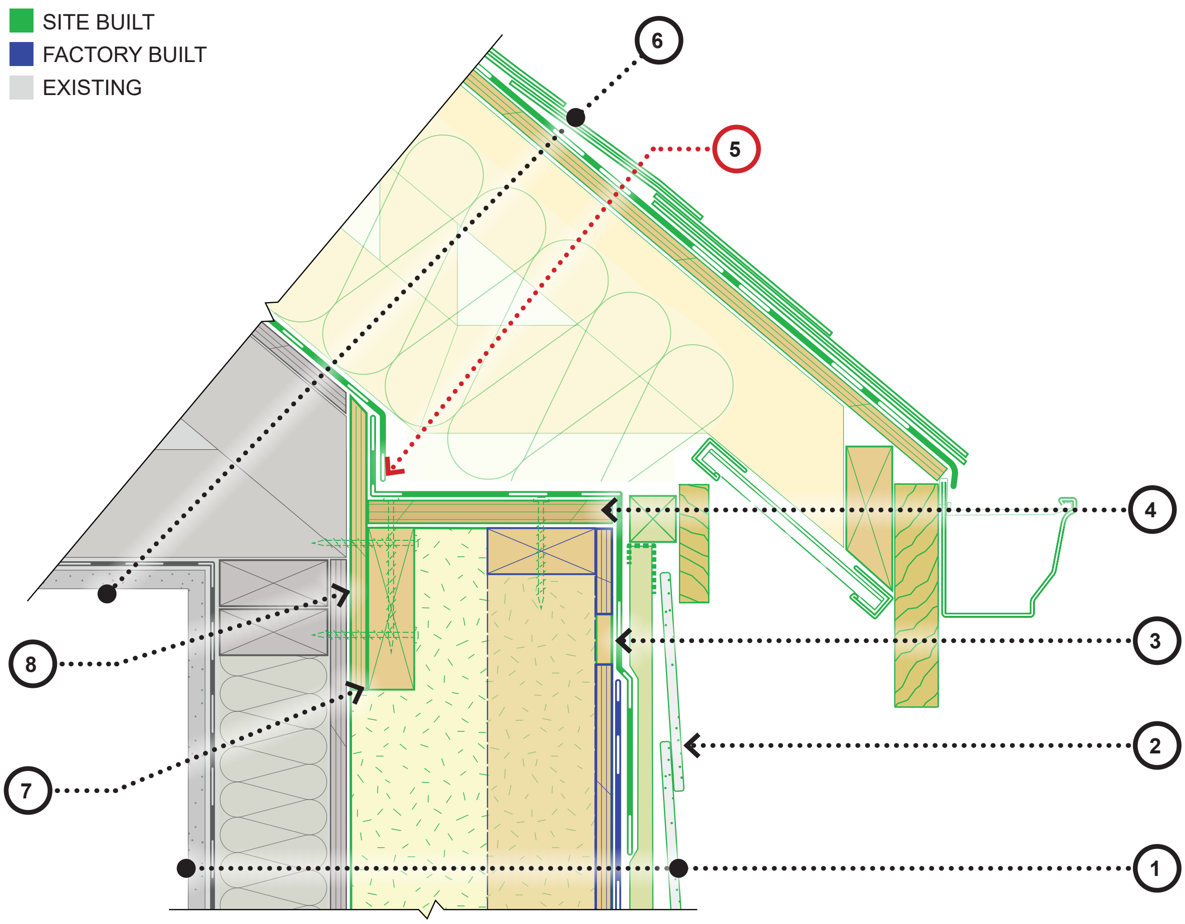


LEGEND

1. 2x4 Framed Assembly.
2. Intermittent insulation fill slot through sheathing spline. Slot to be over-clad after installation of insulation.
3. Site installed self-adhered VP membrane over spline. (AB/WRB)
4. Site installed trim over vertical cladding joints.

Detail A.2–03 | Vertical Panel Joint

PEER Wall A.2 — 2x4 Framed

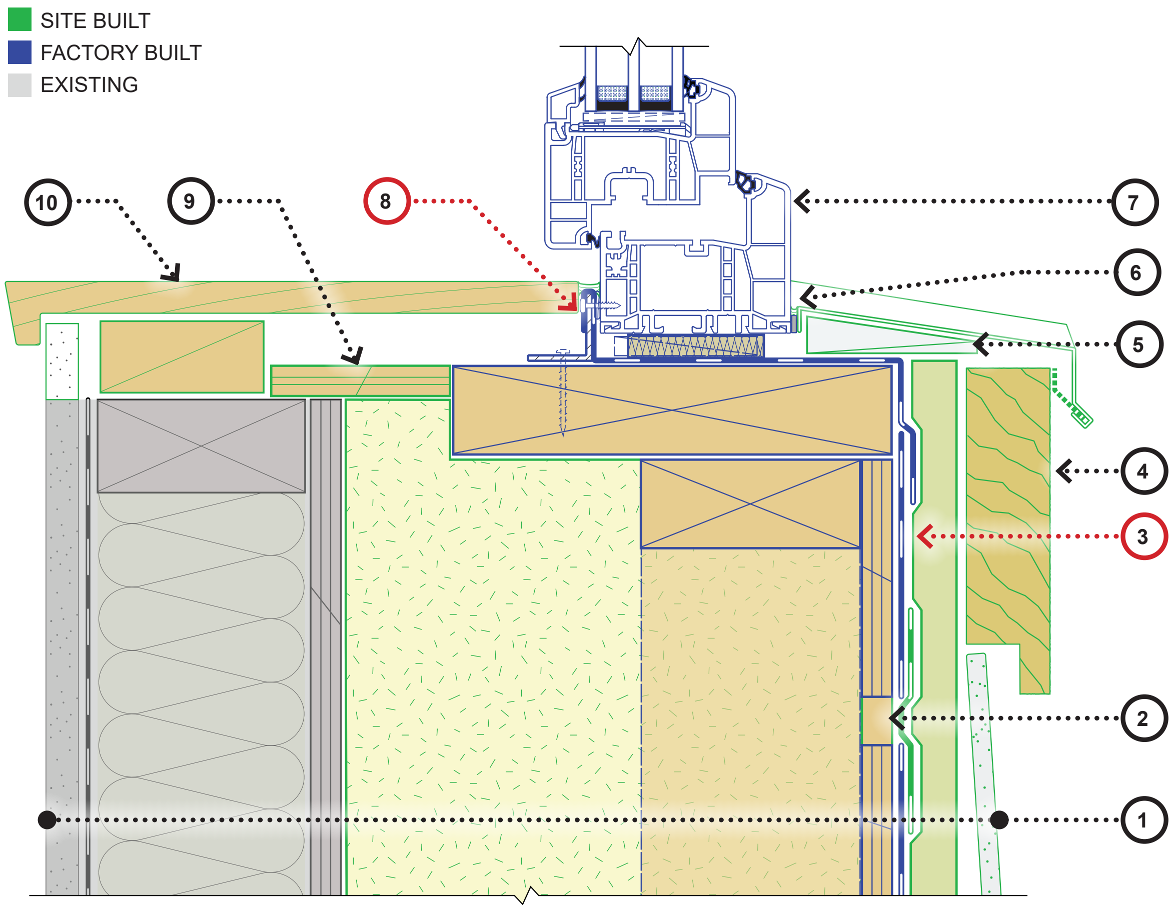


LEGEND

1. 2x4 Framed Assembly.
2. Site-applied closure cladding and trim near top of wall.
3. Intermittent lifting hole and insulation fill slot. Slot to be over-clad after installation of insulation.
4. Rim panel fastened to plywood plumb shim. Panel framing fastened to continuous rim panel.
5. Self-adhered membrane adhered to existing assembly and plumb shim to receive roof membrane. (AB/WRB)
6. Chainsaw retrofit roof assembly.
7. Wood blocking fastened to plywood plumb shim to support rim panel.
8. Plywood plumb shim fastened at cut back existing roof structure (chainsaw retrofit).

Detail A.2–04 | Top of Wall

PEER Wall A.2 — 2x4 Framed

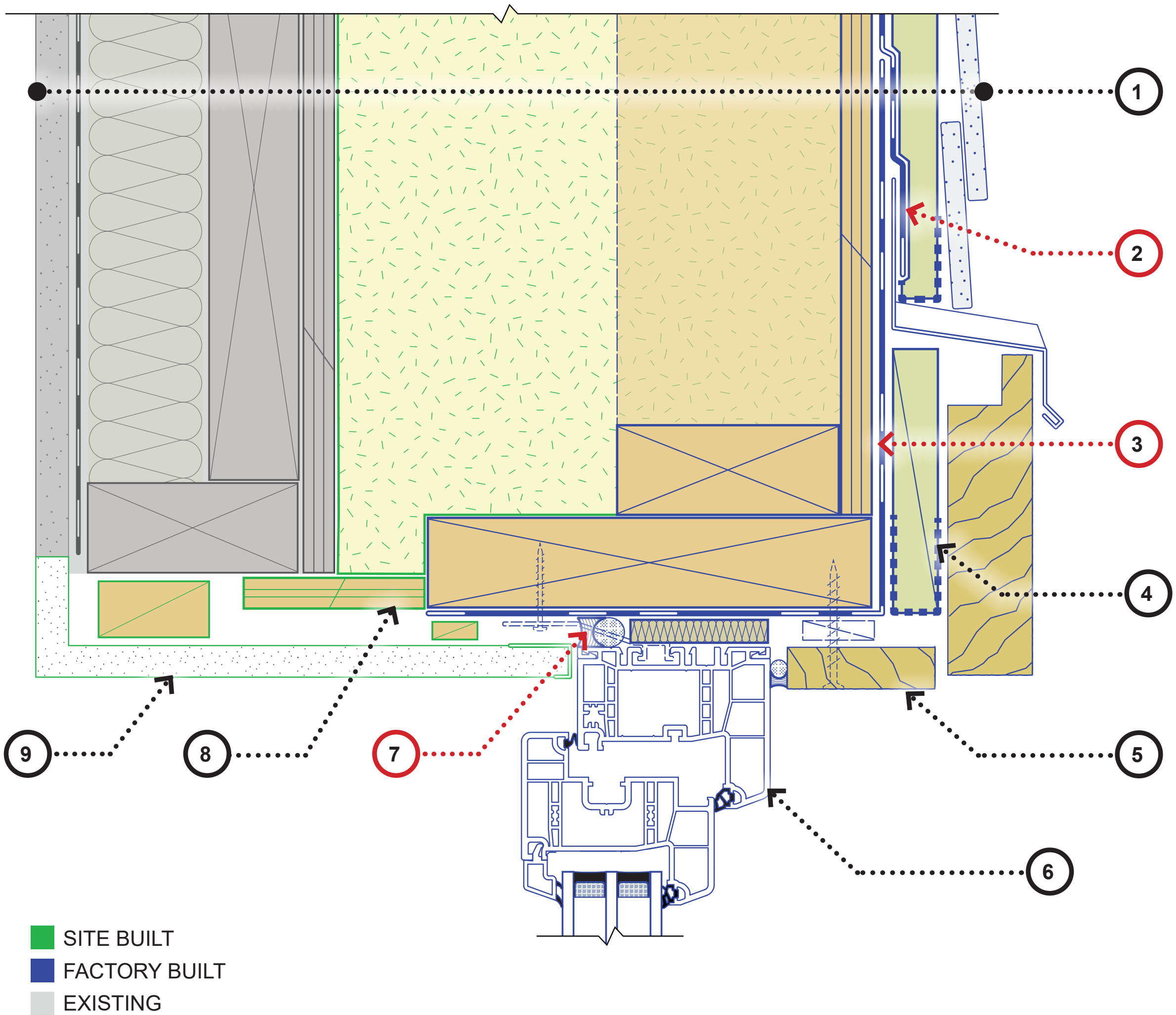


LEGEND

1. 2x4 Framed Assembly.
2. Intermittent lifting hole and insulation fill slot. Slot to be sealed with high performance tape and over-clad after installation of insulation.
3. Self-adhered VP membrane. (AB/WRB)
4. Site-applied closure cladding and trim around window.
5. Intermittent angled foam block to support sill flashing.
6. Window sill flashing clipped to sill trim with perforated metal receiver and adhered to face of window frame with foam tape and sealant.
7. Factory installed triple-glazed window secured in place with sill angle at sill.
8. Window set into continuous sealant against sill angle and secured with screws. (AB/WRB)
9. Plywood shim to tie retrofit with existing assembly.
10. Interior window trim and closure sealant over sill angle as required.

Detail A.2–05 | Window Sill

PEER Wall A.2 — 2x4 Framed



LEGEND

1. 2x4 Framed Assembly.
2. Factory-applied self-adhered membrane over head flashing and lapped over head flashing membrane. (AB/WRB)
3. VP head flashing membrane. (AB/WRB)
4. Factory installed window head prestrip and strapping.
5. Head trim fastened into 2x8 window buck.
6. Factory installed new triple-glazed window secured in place with clips at head and jambs.
7. Continuous sealant installed between rough-opening and window head/jambs.
8. Plywood shim to tie retrofit with existing assembly.
9. Interior gypsum.

Detail A.2–06 | Window Head

PEER Wall A.2 — 2x4 Framed

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A.3 PEER Wall — Nailbase Panel Wall System

Partial Structurally Insulated Panel ("Half-SIP") wall for prefabricated exterior energy retrofit using advanced materials and techniques.

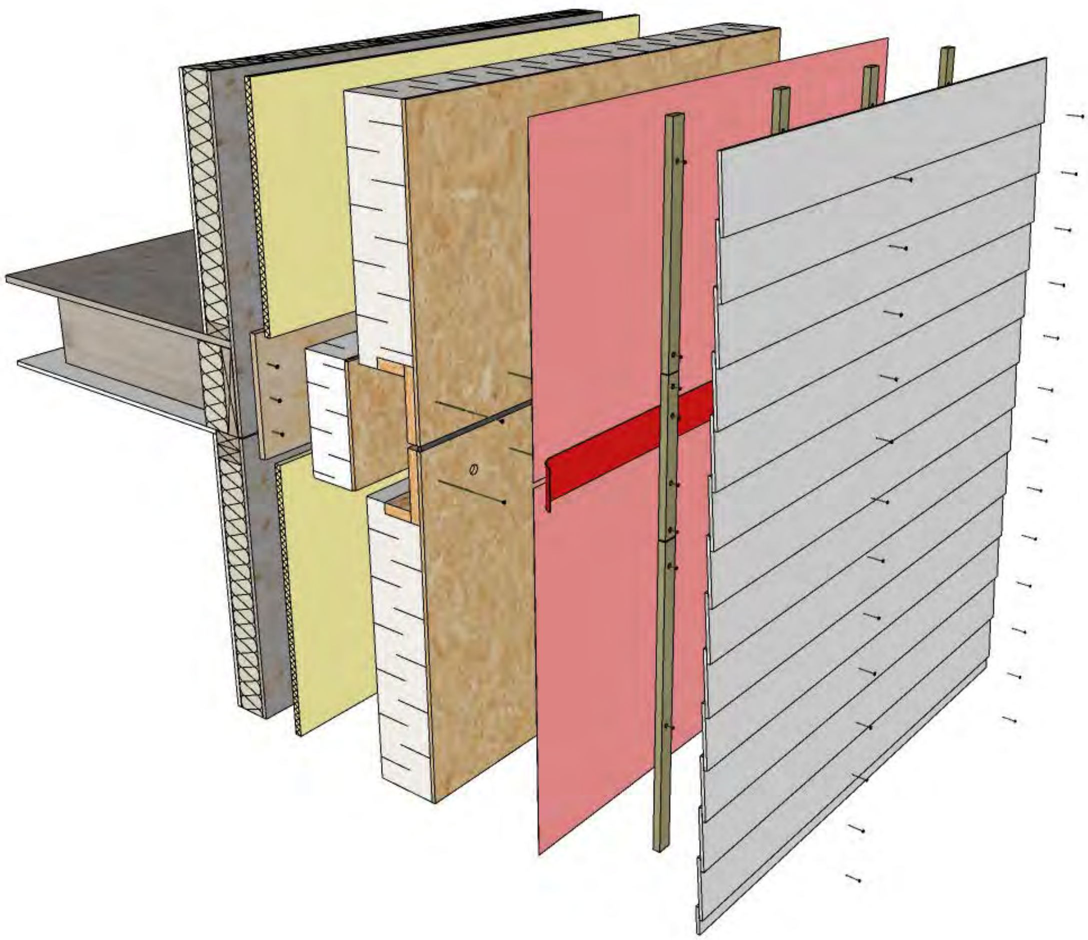

Figure 1 Exploded view of partial retrofit panel components at floor line transition

Developed by Natural Resources Canada's Prefabricated Exterior Energy Retrofit (PEER) team

CanmetENERGY

Canada

A.3 PEER Wall — Half-SIP Enclosure Assembly Overview

The following is a description of the retrofit panel layers installed on the exterior of the existing house. See also the Typical Construction Details on page 5.

Exterior

- Cladding
- Borate-treated strapping + air cavity
- Self-adhered vapour permeable membrane (air barrier and water resistive barrer)
- Half-SIP: Exterior OSB sheathing, EPS insulation, layers glued together
- Compressible mineral fibre gap fill insulation
- Existing assembly (not shown)

Interior

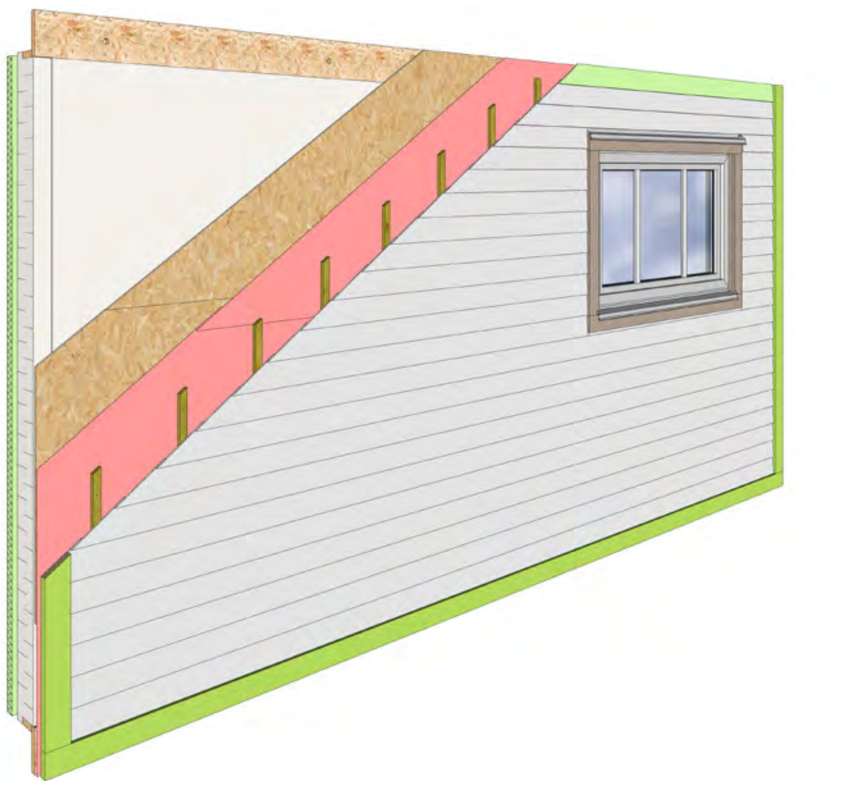

Figure 2 Retrofit half-SIP wall panel overview (green highlights indicate site-applied perimeter joint/tie-in components)

Retrofit Description

- Panels can be installed over the existing wall either with the cladding removed or left in place, and the existing windows and interior trim removed. A fibrous batt insulation layer is installed over the existing assembly to provide for in-out tolerance of the panel installation while baffling the small space between the panel and the existing wall.
- Half-SIPs are mechanically fastened to a continuous insulated box beam supported by intermittent foundation brackets at the base of the above grade wall, a rim panel at the following storey floor line, and to a plywood plumb shim at the roofline.
- The air barrier/weather resistive barrier (AB/WRB, denoted with red callouts in the details) is a factory-installed self-adhered membrane at the exterior OSB sheathing, with various edges returning into joints and face sealed with compatible pressure sensitive acrylic tape.
- New windows (and their trim/closures) can be pre-installed into the panels at the factory or site installed after panel placement to accommodate for tolerances. Window AB/WRB transition/rough-opening membranes are factory installed on the half-SIP.
- The drained and ventilated rainscreen cladding comes pre-installed except at panel joints and at window interfaces (if site installed).
- Closure cladding, flashing, and trim is installed as required at panel joints and windows.

Potential Benefits of an Exterior Half-SIP Retrofit

- All work (except interior window trim) is done from the exterior leaving the home livable during construction.
- Site installation work is limited, reducing installation times and disruption to residents.
- Eliminates on-site framing and uses manufactured panels to simplify installation.
- Insulation thickness can be varied to accommodate energy performance goals and lot-line setbacks.
- Provides a layer of continuous insulation reducing thermal bridging through framing.
- Increases air tightness, reduces drafts and noise, and lowers energy costs.
- Reduces potential for moisture ingress with careful detailing.
- Provides opportunity for seismic upgrades to meet regional requirements.
- The structural rigidity provided by half-SIPs allow for larger panels and provide some load bearing capacity for exterior window installation.
- Allows for quality control of the air barrier system at the factory before it is covered with cladding.
- Allows for quality assurance of the air barrier system transitions on site prior to installing closure cladding.
- Absence of inner OSB skin reduces condensation and mould growth risk compared to a full SIP.

Key Considerations

Air sealing: The air barrier (AB) is provided by the membrane at the exterior side of the half-SIP. Flexible membrane flashings around panel joints, windows, doors, and other penetrations and transitions complete the AB. Sealing at the top plate and base-of-wall where the new wall connects to the existing house is also required. Openings around electrical, mechanical, and other service penetrations are sealed throughout the construction process. These are critical details to ensure an airtight barrier.

Connection to existing structure: This retrofit uses structural brackets and a continuous box beam at the base of the above grade wall to support the first floor half-SIP at its base. A rim panel at the floor line of the following storey is attached to the existing structure and provides support for the top of the first floor half-SIP and bottom of the second storey half-SIP. Long screws through the half-SIP into a plywood plumb shim and existing building framing produces a self-supporting sandwich at the top of the second storey half-SIP. Windows moved to the exterior provide for easy sealing to the AB/WRB.

Water control: The membrane on the exterior OSB sheathing of the half-SIP acts as the water resistive barrier (WRB). Vertical strapping is factory installed over the WRB to provide a rainscreen cavity behind the cladding.

Cladding: This system must be easily transported and therefore only allows for lighter cladding materials. Materials such as cement board or pre-finished wood are factory installed directly to the strapping. Site install of some cladding around panel joints and windows may be required.

Durability: The half-SIP panels will have a reduced drying potential dependant on the thickness of the EPS insulation. Applications should be modelled to assess risk.

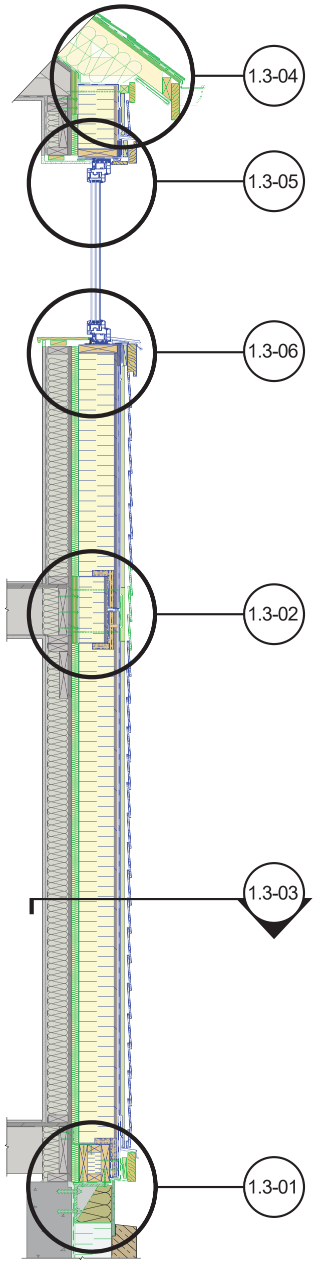

Figure 3 House section detail wayfinder.

Typical Construction Details

The sample details shown in the following pages are intended to illustrate typical transition approaches both for air barrier and panel/insulation continuity. Note that these are example details, and project-specific details should always be developed to account for the unique conditions of each project.

The annotations and legend in each sample detail contains red “AB” and "AB/WRB" icons to indicate the various air barrier and where applicable water resistive barrier components are present.

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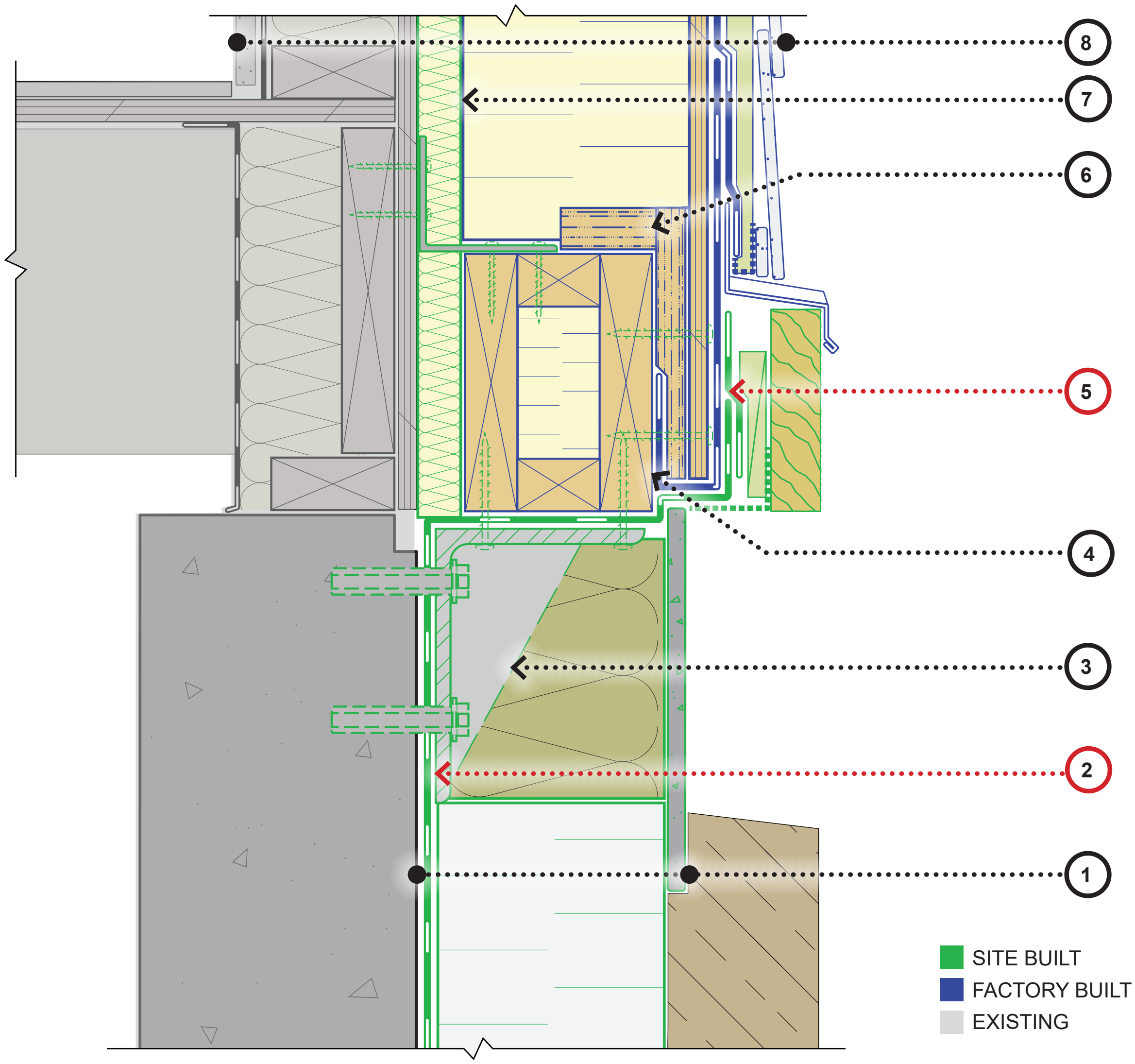
- SITE BUILT
- FACTORY BUILT
- EXISTING

List of Details

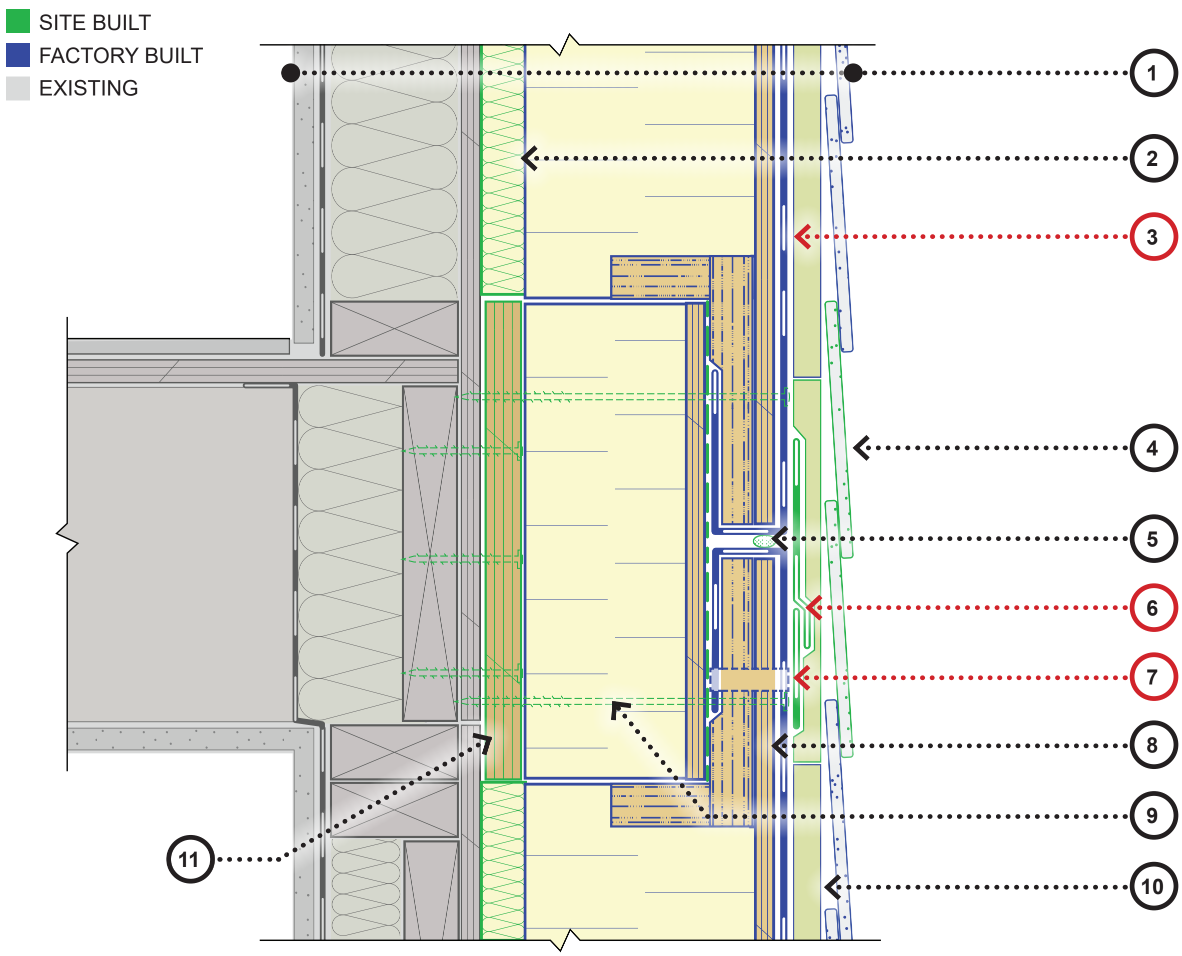


LEGEND

1. Below-grade wall assembly:
   - Fiber cement board
   - EPS foam insulation
   - Self-adhered transition membrane (AB/WRB)
   - Existing assembly
2. Pre-strip transition membrane prior to foundation bracket install. (AB/WRB)
3. Intermittent foundation bracket surrounded with mineral wool insulation.
4. Continous insulated box beam fastened to existing structure with intermittent deck ties.
5. Pre-strip transition membrane reverse lapped over self-adhered VP membrane with leading edges sealed using high performcane tape. (AB/WRB)
6. LSL plates at base of half-SIP fastened to box beam.
7. Compressed fibreglass insulation ("Squishy Layer").
8. Nailbase Wall Assembly.

Detail A.3–01 | Base of Wall at Foundation

PEER Wall A.3 — Nailbase SIP

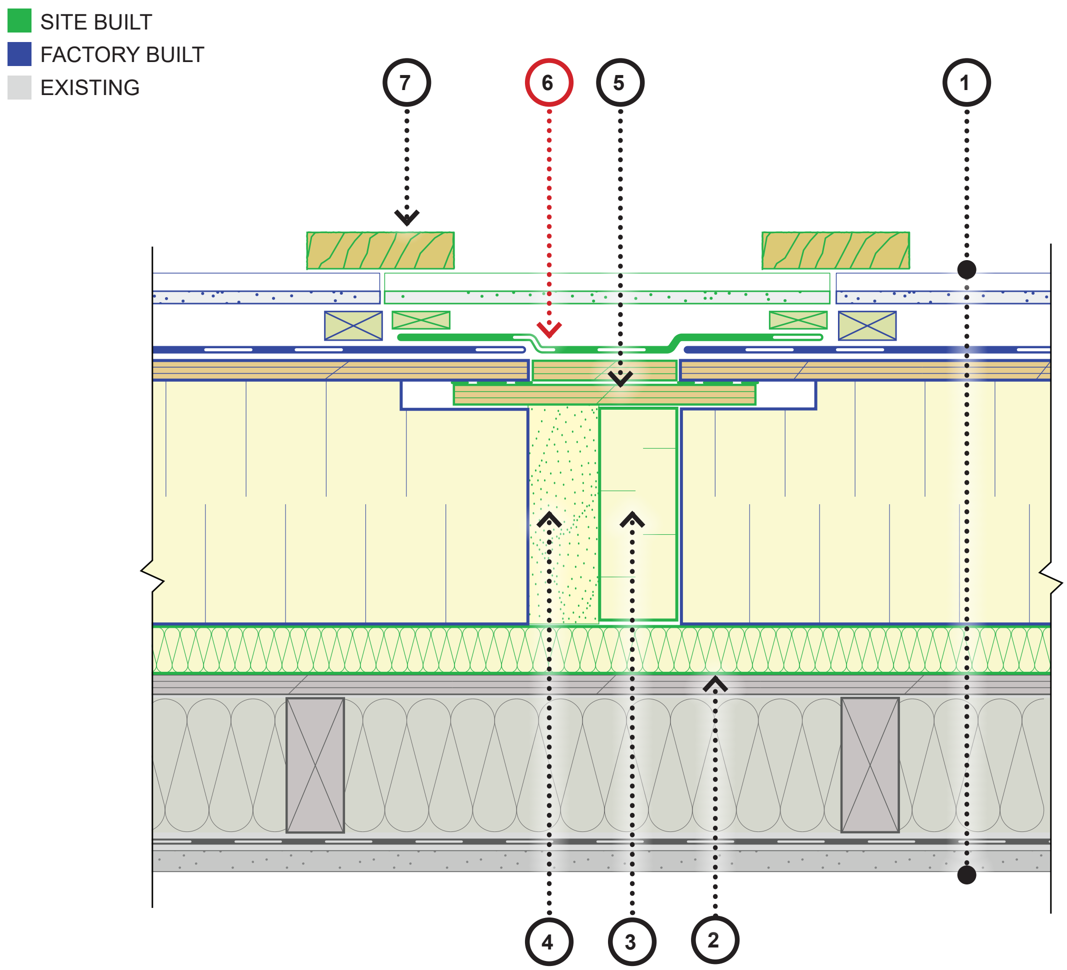


LEGEND

1. Nailbase Wall Assembly.
2. Compressible mineral fibre gap fill insulation.
3. Self-adhered VP membrane. (AB/WRB)
4. Site applied cladding across joint.
5. Backer rod between floor panels.
6. Second floor self-adhered VP membrane sealed to first floor membrane with high performance tape. (AB/WRB)
7. Reinforced lifing hole in top of SIP splines, sealed with high performance tape. (AB/WRB)
8. LSL framing at half-SIP panels fastened and adhered to rim panel with construction adhesive.
9. Continuous rim panel fastened to plywood plumb shim.
10. Factory installed strapping for panel. Cladding site installed above window head.
11. Plywood plumb shim fastened to existing structure at floorline.

Detail A.3–02 | Horizontal Panel Joint

PEER Wall A.3 — Nailbase SIP

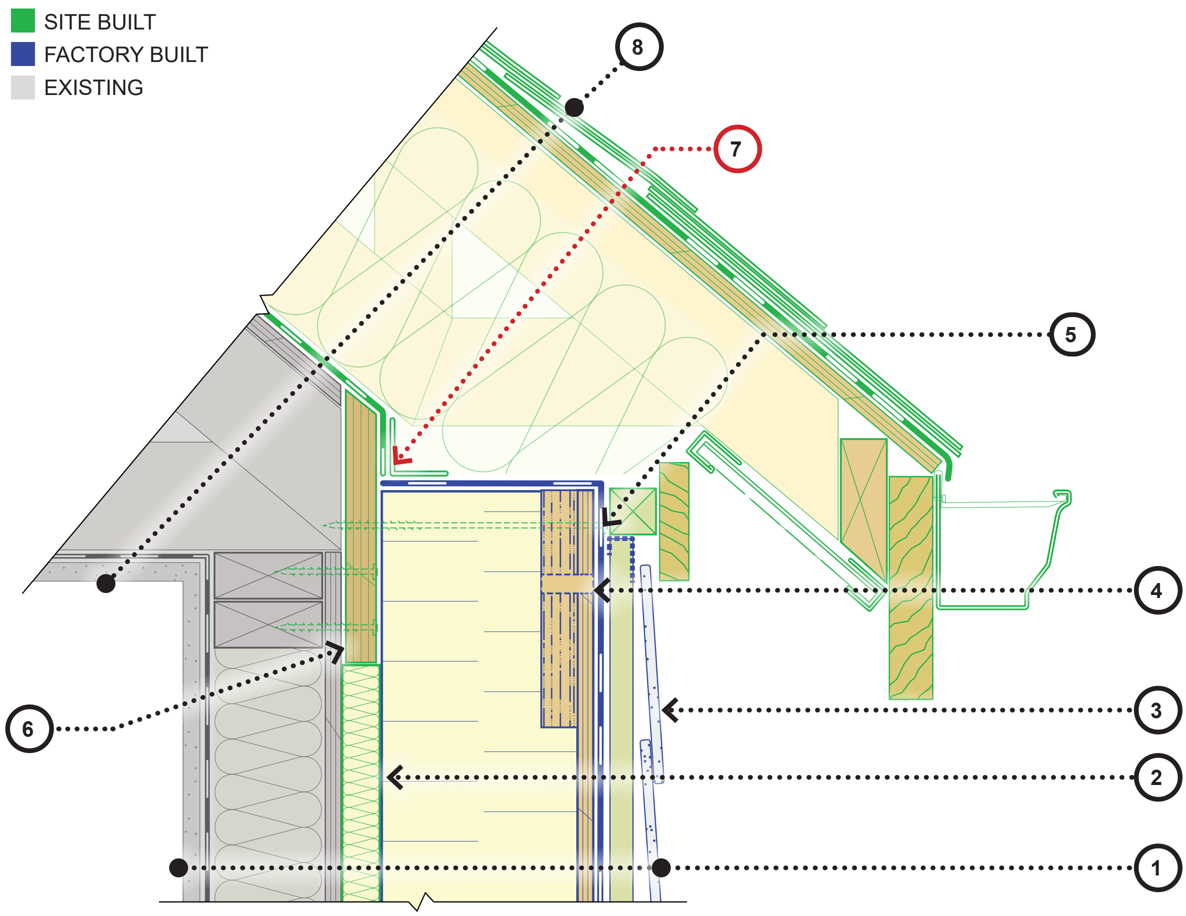


LEGEND

1. Nailbase Wall Assembly.
2. Compressible mineral fibre gap fill insulation.
3. EPS filler block.
4. Self-expanding foam joint sealant.
5. Front splines glued in place.
6. Site installed self-adhered VP membrane over splines. (AB/WRB)
7. Site installed trim over vertical cladding joints.

Detail A.3–03 | Vertical Panel Joint

PEER Wall A.3 — Nailbase SIP

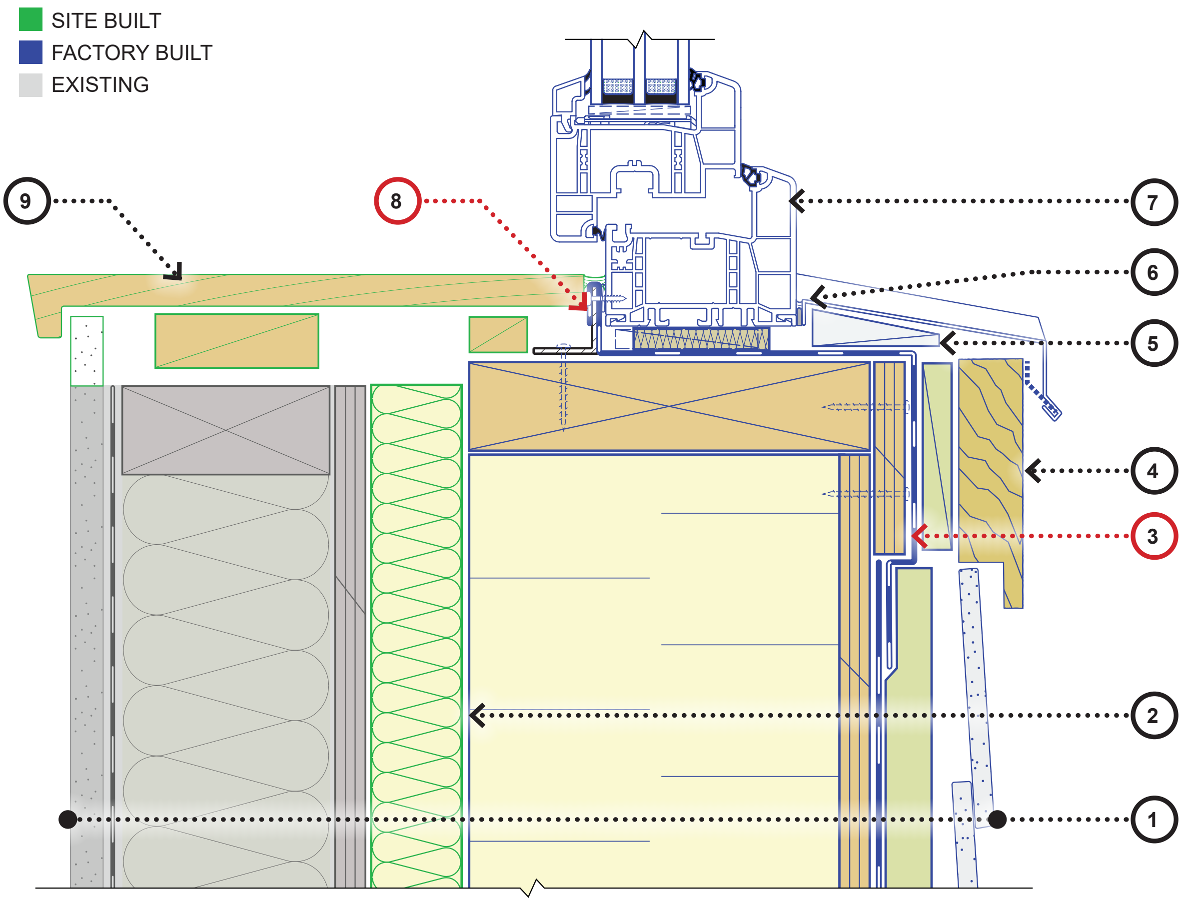


LEGEND

1. Nailbase Wall Assembly.
2. Compressible mineral fibre gap fill insulation.
3. Factory-applied closure cladding and trim near top of wall.
4. Lifting holes through exterior sheathing and LSL beam.
5. Panel fastened to existing roof structure.
6. Plywood plumb shim fastened at cut back existing roof structure (chainsaw retrofit).
7. High performance tape sealed to factory installed self-adhered membrane adhered membrane and roof assembly membrane. (AB/WRB)
8. Chainsaw retrofit roof assembly.

Detail A.3–04 | Top of Wall

PEER Wall A.3 — Nailbase SIP

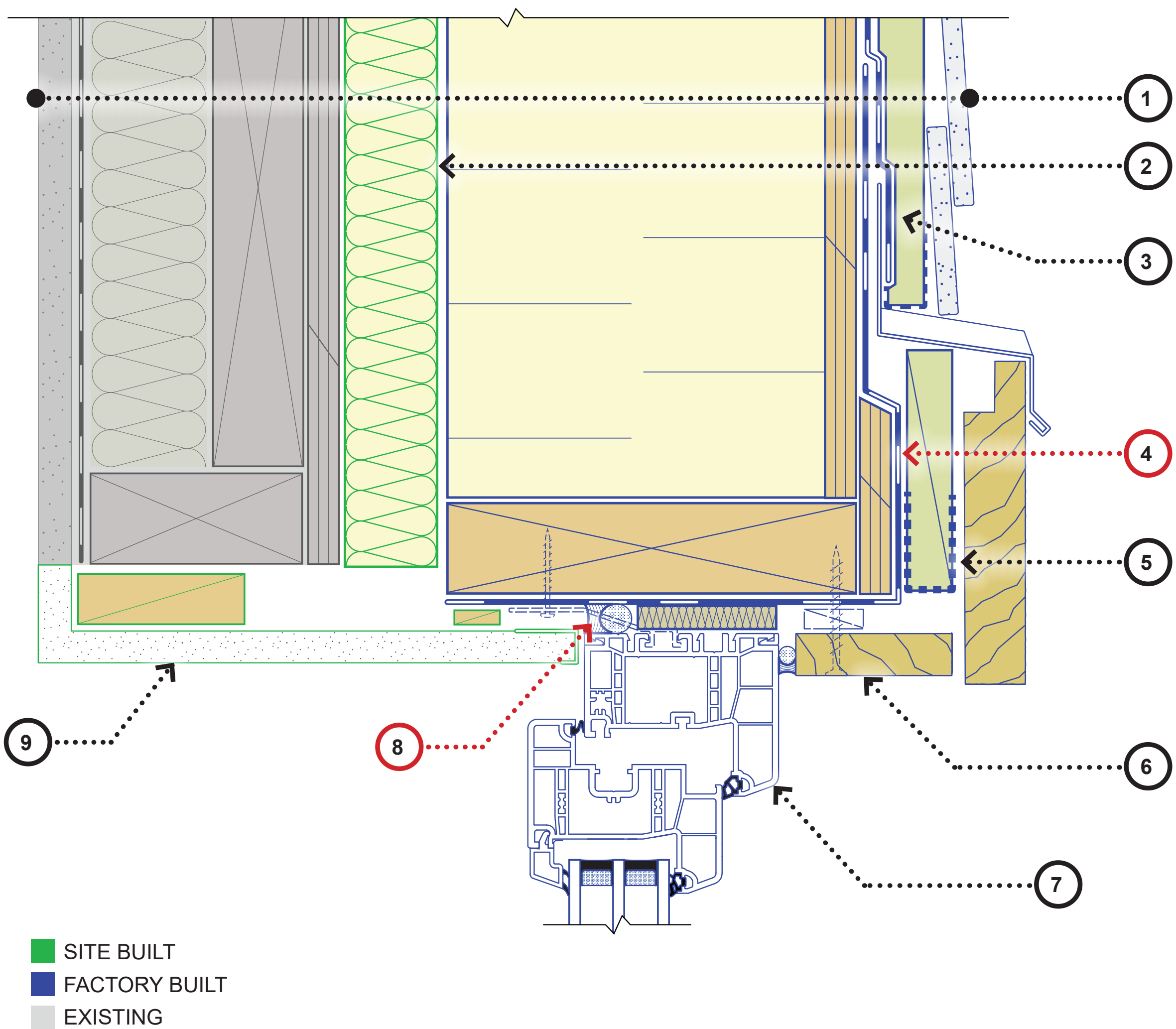


LEGEND

1. Nailbase Wall Assembly.
2. Compressible mineral fibre gap fill insulation.
3. Self-adhered sill membrane over sill angle and lapped onto field membrane. (AB/WRB)
4. Factory-applied closure cladding and trim around window.
5. Intermittent angled foam block to support sill flashing.
6. Window sill flashing clipped to sill trim with perforated metal receiver and adhered to face of window frame with foam tape and sealant.
7. Factory installed new triple-glazed window secured in place with sill angle at sill.
8. Factory installed window set into continuous sealant over sill angle and secured with screws. (AB/WRB)
9. Interior window trim and closure sealant over sill angle as required.

Detail A.3–05 | Window Sill

PEER Wall A.3 — Nailbase SIP



LEGEND

1. Nailbase Wall Assembly.
2. Compressible mineral fibre gap fill insulation.
3. Factory installed closure cladding and self-adhered membrane over head flashing and lapped over head flashing membrane. (AB/WRB)
4. VP head flashing membrane. (AB/WRB)
5. Factory installed window head prestrip and strapping.
6. Head trim toe nailed into 2x8 window buck.
7. Factory installed new triple-glazed window secured in place with clips at head and jambs.
8. Continuous sealant installed between rough-opening and window head/jambs.
9. Interior gypsum.

Detail A.3–06 | Window Head

PEER Wall A.3 — Nailbase SIP

Natural Resources Canada / Ressources naturelles Canada

A.4 PEER Wall — I-Joist Framed Panel Wall System

Framed panel for prefabricated exterior energy retrofit using advanced materials and techniques.

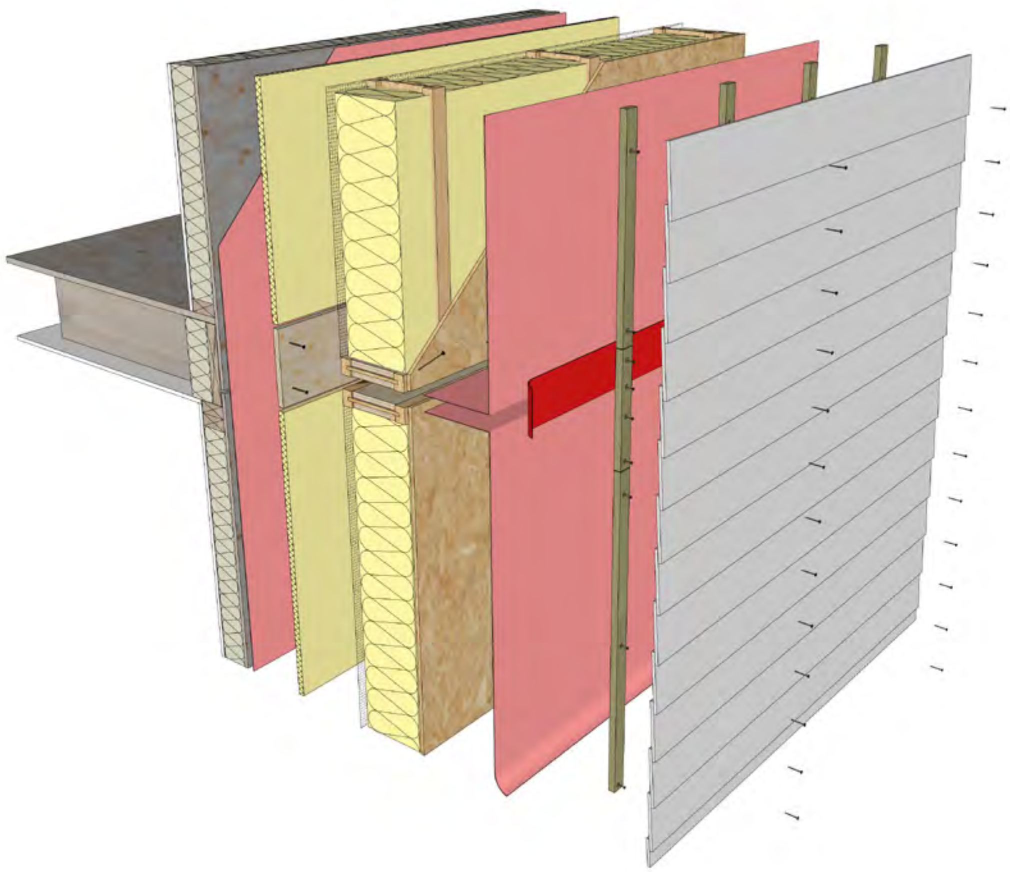


Figure 1 Exploded view of partial retrofit panel components at floor line transition

Developed by Natural Resources Canada's Prefabricated Exterior Energy Retrofit (PEER) team

CanmetENERGY

Canada

A.4 PEER Wall — I-Joist Framed Enclosure Assembly Overview

The following is a description of the retrofit panel layers installed on the exterior of the existing house. See also the Typical Construction Details on page 5.

Exterior

- Cladding
- Borate-treated strapping + air cavity
- Self-adhered vapour permeable membrane (water resistive barrer)
- Wall sheathing
- I-Joist with fibrous batt insulation and retaining mesh
- Compressible mineral fibre gap fill insulation
- Existing assembly with self-adhered vapour permeable membrane (air barrier) (not shown)

Interior

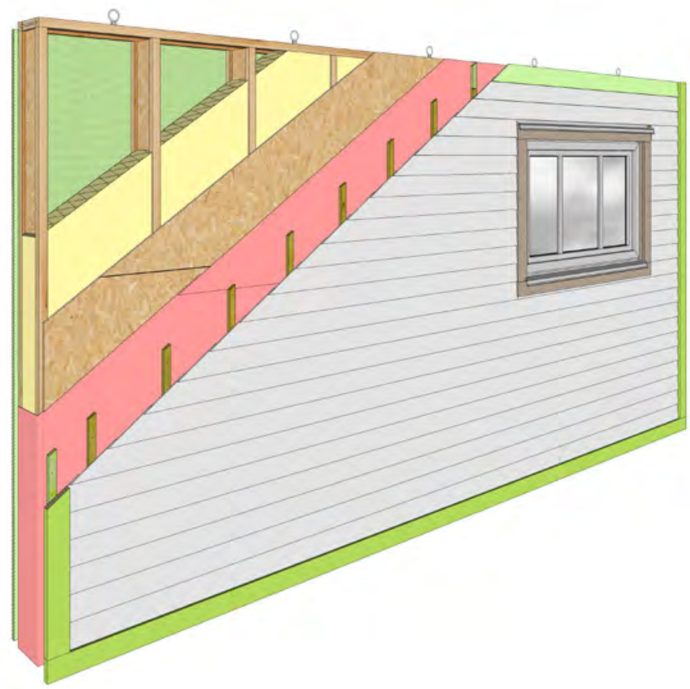


Figure 2 Retrofit I-Joist wall panel overview (green highlights indicate site-applied perimeter joint/tie-in components)

Retrofit Description

- Panels can be installed over the existing wall either with the cladding removed or left in place, and the existing windows and interior trim removed. A fibrous batt insulation layer is installed over the existing assembly to provide for in-out tolerance of the panel installation while baffling the small space between the panel and the existing wall.
- I-Joist panels with batt insulation between studs are fastened to a continuous insulated box beam supported by intermittent foundation brackets at the base of the above grade wall, and plywood plumb shims at the following storey floor line, and the roof line.
- The air barrier (AB, denoted with red callouts in the details) is a vapour permeable self-adhered membrane applied on site to the existing sheathing.
- The weather resistive barrier (WRB, denoted with red callouts in the details) is a self-adhered vapour permeable membrane adhered to the panel's exterior sheathing.
- New windows (and their trim) can be pre-installed into the panels at the factory or site installed after panel placement to accommodate for tolerances. Window and door AB/WRB transition membranes are installed on site between the air barrier membrane and window flashing membranes.
- The drained and vented rainscreen cladding comes pre-installed except at panel joints and at window interfaces (if site installed).
- Closure cladding, flashing, and trim is installed as required at panel joints and windows.

Potential Benefits of an I-Joist Framed + Batt Insulation Retrofit

- All work (except interior window trim) is done from the exterior leaving the home livable during construction.
- Site installation work is limited, reducing installation times and disruption to residents.
- Eliminates on-site framing and using manufactured panels simplifies installation.
- Insulation thickness can be varied (limited to I-Joist depths) to accommodate energy performance goals and lot-line setbacks.
- The structural rigidity provided by framed panels allow them to be built larger and provide some load bearing capacity for exterior window installation.
- Increases air tightness, reduces drafts and noise, and lowers energy costs.
- Reduces potential for moisture ingress with careful detailing.
- Improved tolerence to water ingress and drying potential compared to a rigid foam based retrofit.
- Provides opportunity for seismic upgrades to meet regional requirements.
- Allows for quality control of the air barrier system at the factory before it is covered with cladding.
- Allows for quality assurance of the air barrier system transitions on site prior to installing closure cladding.

Key Considerations

Air sealing: The air barrier (AB) is provided by the membrane installed on the existing sheathing. This reduces the risk of air leakage into the panel cavities that can result in moisture accumulation. Flexible membrane flashings around windows, doors, and other penetrations and transitions complete the AB. Sealing at the top plate and foundation where the new wall connects to the existing house is also required. The openings around the electrical, mechanical, and other penetrations are sealed throughout the construction process. These are critical details to ensure an airtight barrier.

Connection to existing structure: This retrofit uses structural brackets and a continuous box beam at the base of the above grade wall to support the first floor panel at its base. The tops of the panels are fastened to the existing structure at the second storey floor line and roofline using plywood plumb shims and metal straps. The bottom of the second storey panel is toe screwed to the top of the first storey panel.

Water control: The membrane on the exterior sheathing of the panel acts as the water resistive barrier (WRB). Strapping is factory installed over the WRB and fastened to wall framing to provide a rainscreen cavity behind the cladding.

Cladding: This system must be easily transported and therefore only allows for lighter cladding materials. Materials such as cement board or pre-finished wood are factory installed directly to the strapping. Site install of some cladding around panel joints and windows may be required.

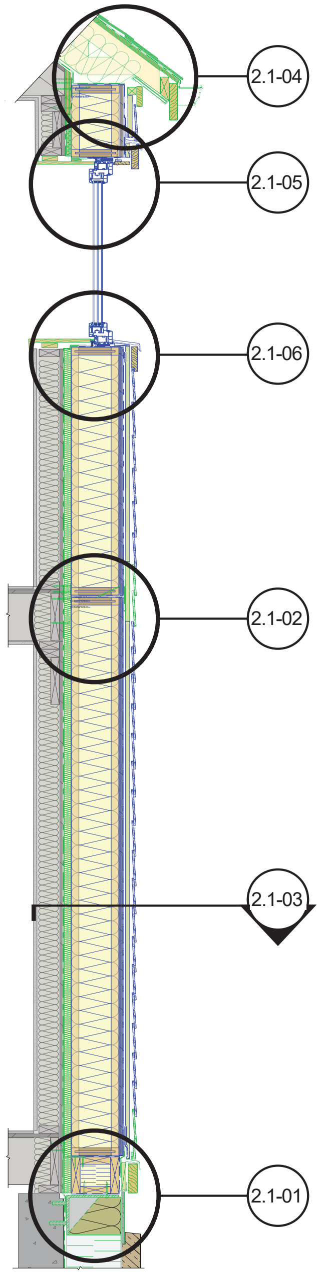


Figure 3 House section detail wayfinder.

Typical Construction Details

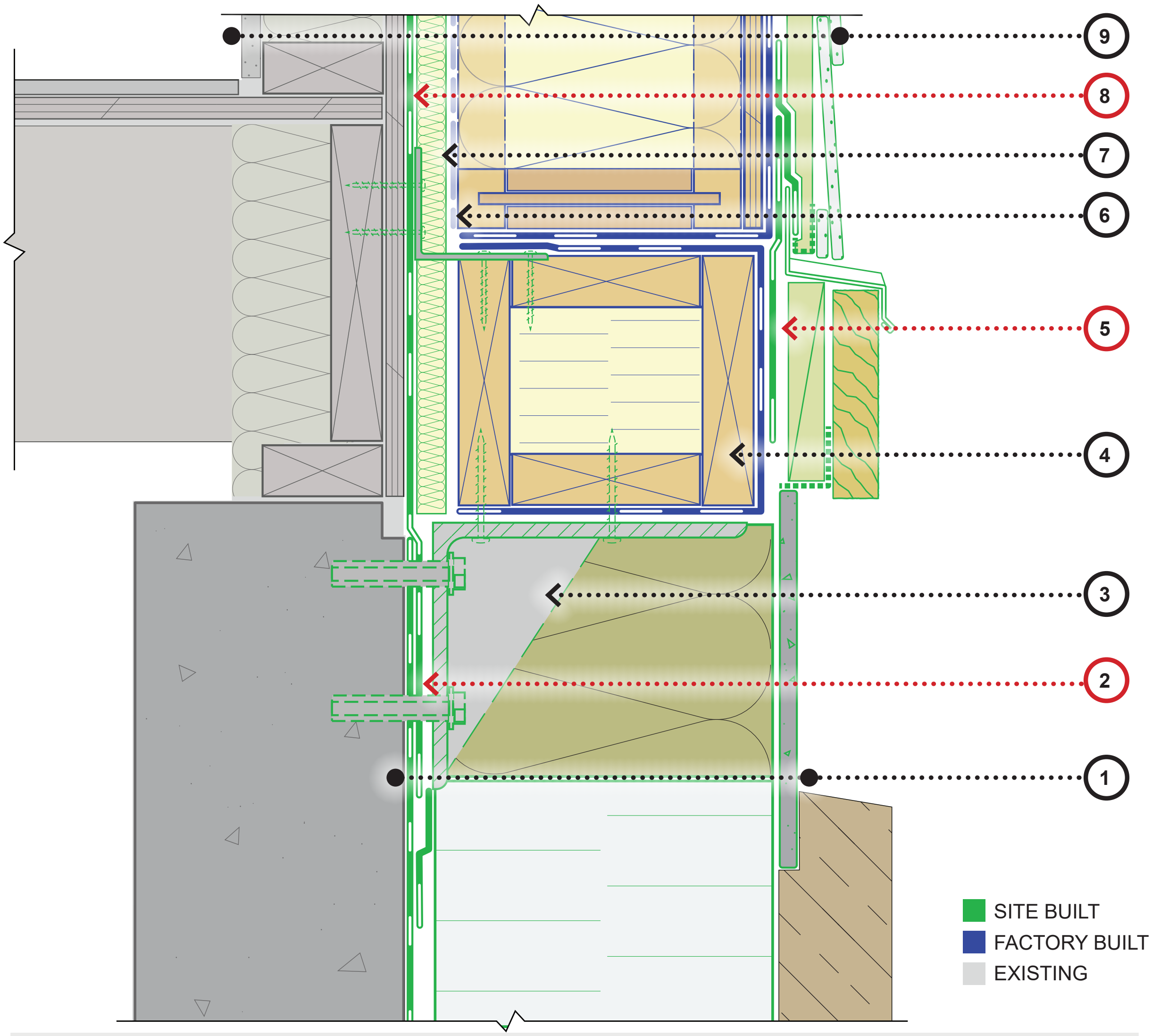
The sample details shown in the following pages are intended to illustrate typical transition approaches both for air barrier and panel/insulation continuity. Note that these are example details, and project-specific details should always be developed to account for the unique conditions of each project.

The annotations and legend in each sample detail contains red "AB" and "WRB" icons to indicate the various air barrier and where applicable water resistive barrier components are present.

Pink lines indicate factory-installed insulation mesh. Each detail also include a colour legend as follows for the grey, green, and blue components shown:

- SITE BUILT
- FACTORY BUILT
- EXISTING

List of Details

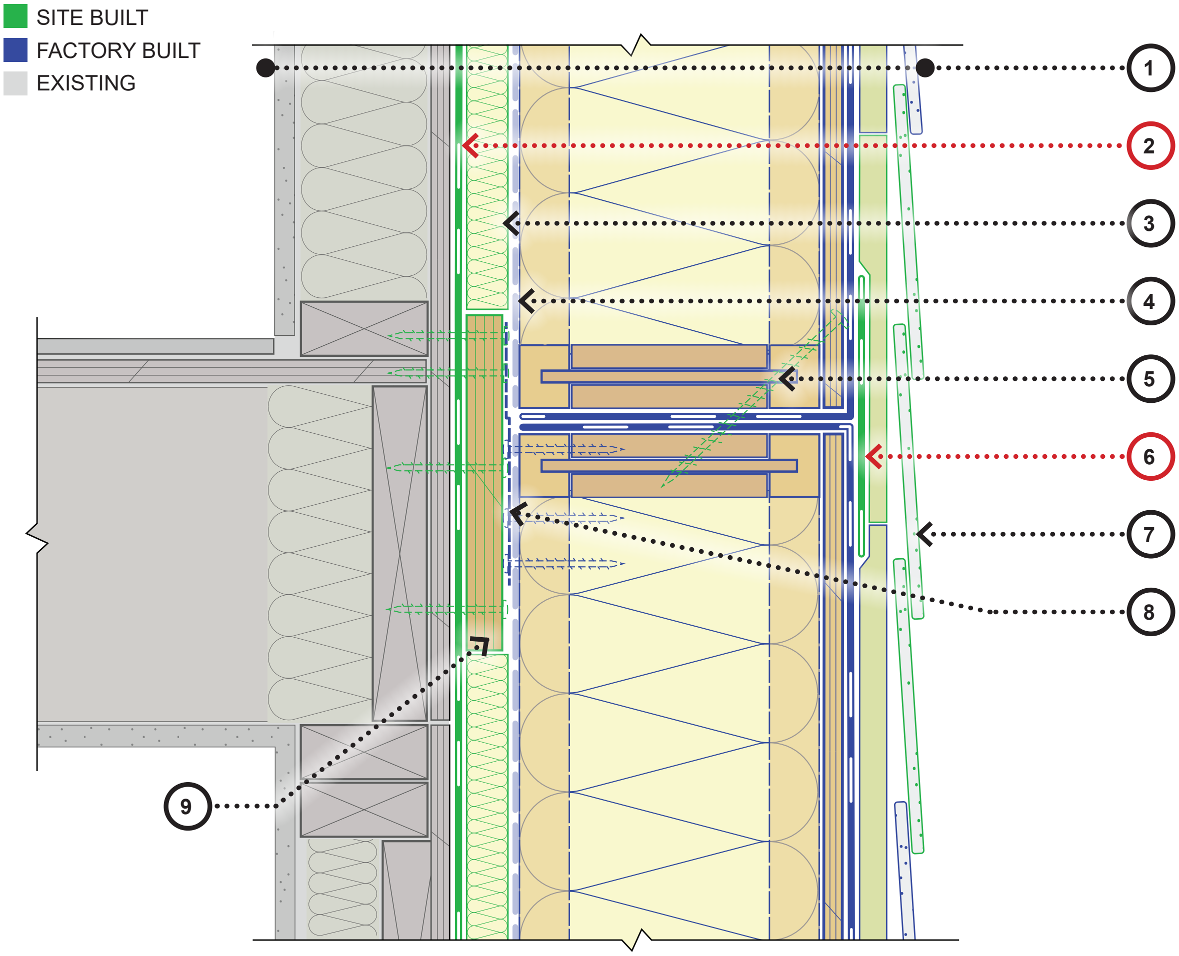


LEGEND

1. Below-grade wall assembly:
   - Fiber cement board
   - EPS foam insulation
   - Self-adhered transition membrane (AB/WRB)
   - Existing assembly
2. Pre-strip transition membrane prior to foundation bracket install. (AB/WRB)
3. Intermittent foundation bracket surrounded with mineral wool insulation.
4. Continous insulated box beam fastened to existing structure with intermittent deck ties.
5. Self-adhered VP membrane lapped over box beam. Leading edge sealed with high performance tape at base of wall flashing. (WRB)
6. Retaining mesh for batt insulation.
7. Compressible mineral fibre gap fill insulation.
8. Self-adhered VP membrane adhered to existing sheathing. (AB)
9. I-Joist Framed Panel Wall Assembly.

Detail A.4–01 | Base of Wall at Foundation

PEER Wall A.4 — I-Joist Panel

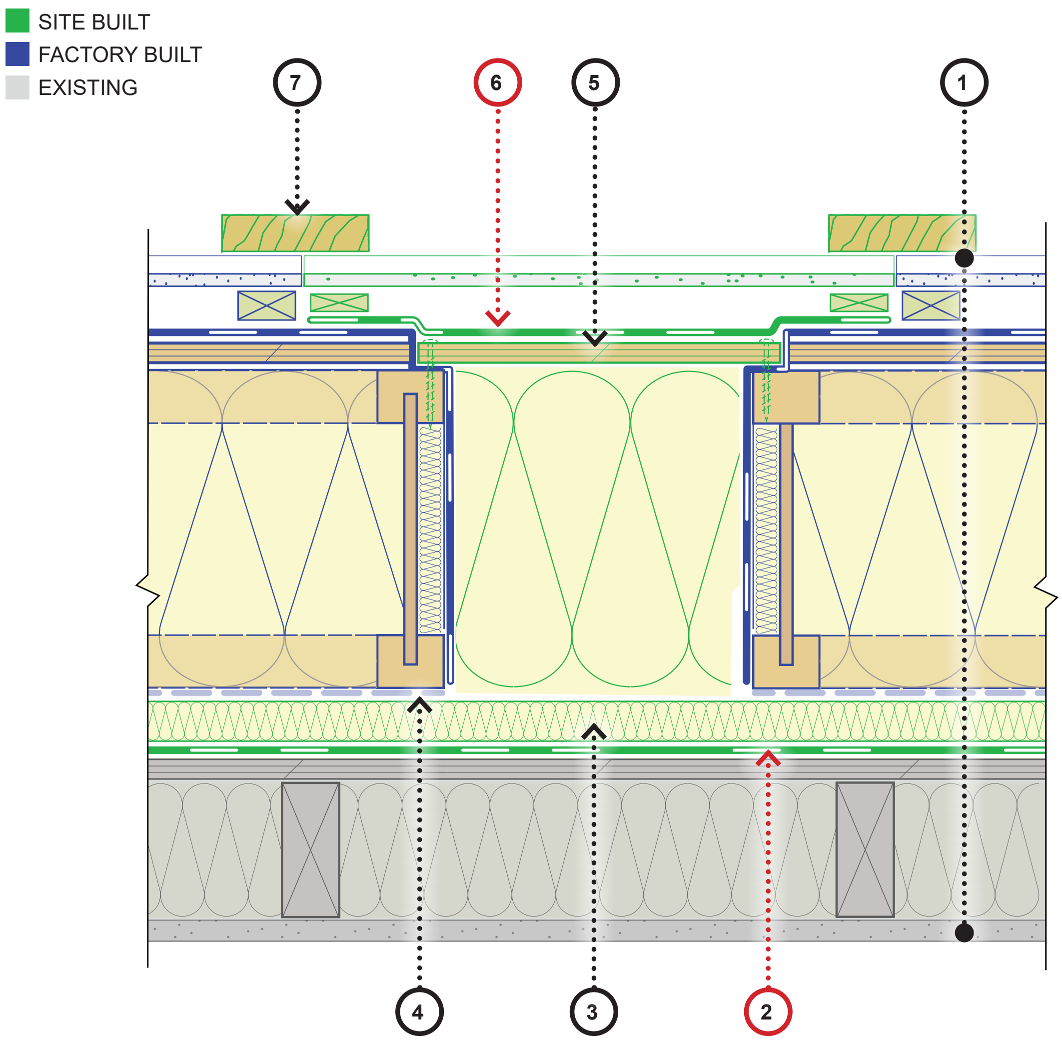


LEGEND

1. I-Joist Framed Panel Wall Assembly.
2. Self-adhered VP membrane adhered to existing sheathing. (AB)
3. Compressible mineral fibre gap fill insulation.
4. Retaining mesh for batt insulation.
5. Screw toe-nailed through bottom plate into top plate of first floor panel.
6. Second floor VP membrane sealed to first floor membrane with high performance tape. (WRB)
7. Site applied cladding across joint.
8. Intermittent lifting strap secured to plywood plumb shim.
9. Plywood plumb shim fastened to existing structure at floorline.

Detail A.4–02 | Horizontal Panel Joint

PEER Wall A.4 — I-Joist Panel

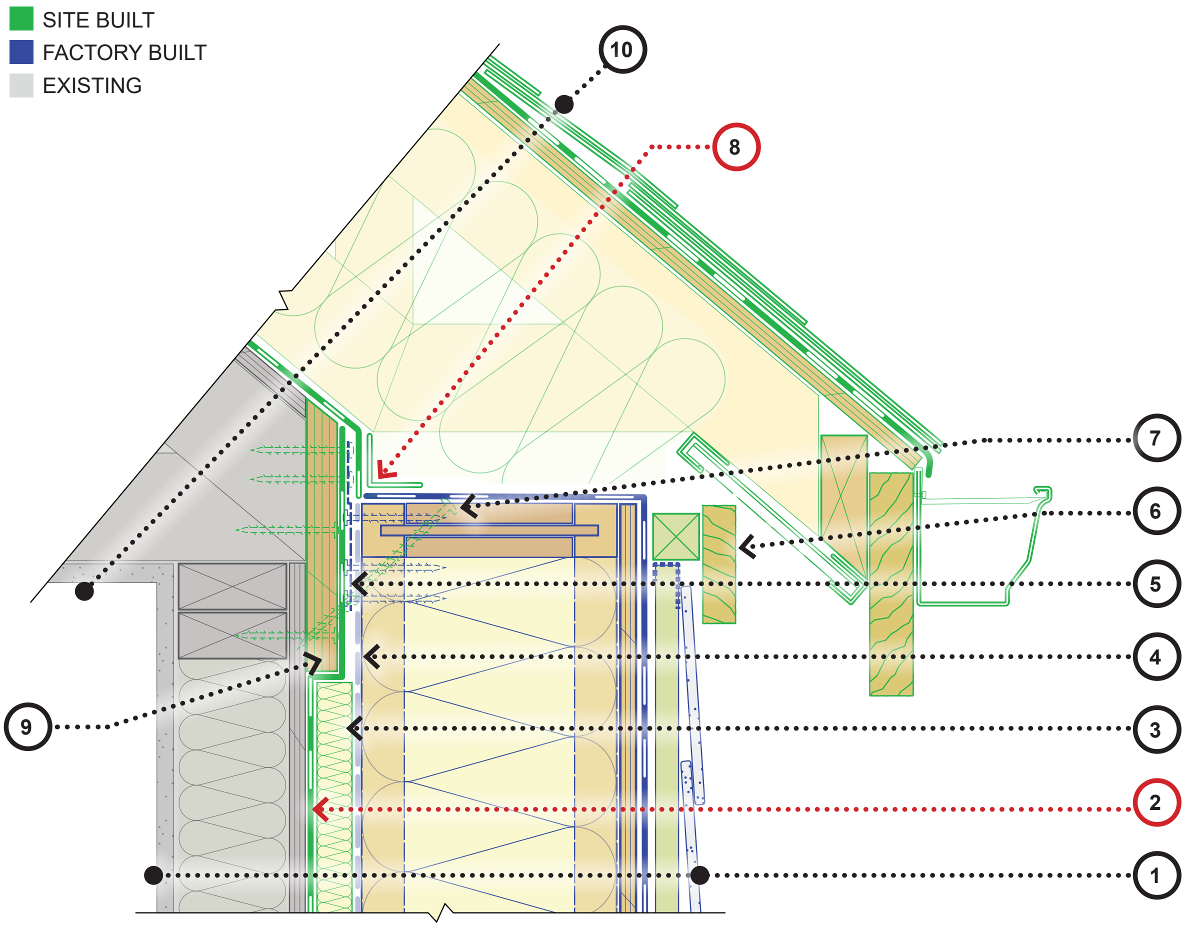


LEGEND

1. I-Joist Framed Panel Wall Assembly.
2. Self-adhered VP membrane adhered to existing sheathing. (AB)
3. Compressible mineral fibre gap fill insulation.
4. Retaining mesh for batt insulation.
5. Plywood spline fastened to panel framing.
6. Self-adhered VP membrane. (WRB)
7. Trim installed over vertical cladding joints.

Detail A.4–03 | Vertical Panel Joint

PEER Wall A.4 — I-Joist Panel

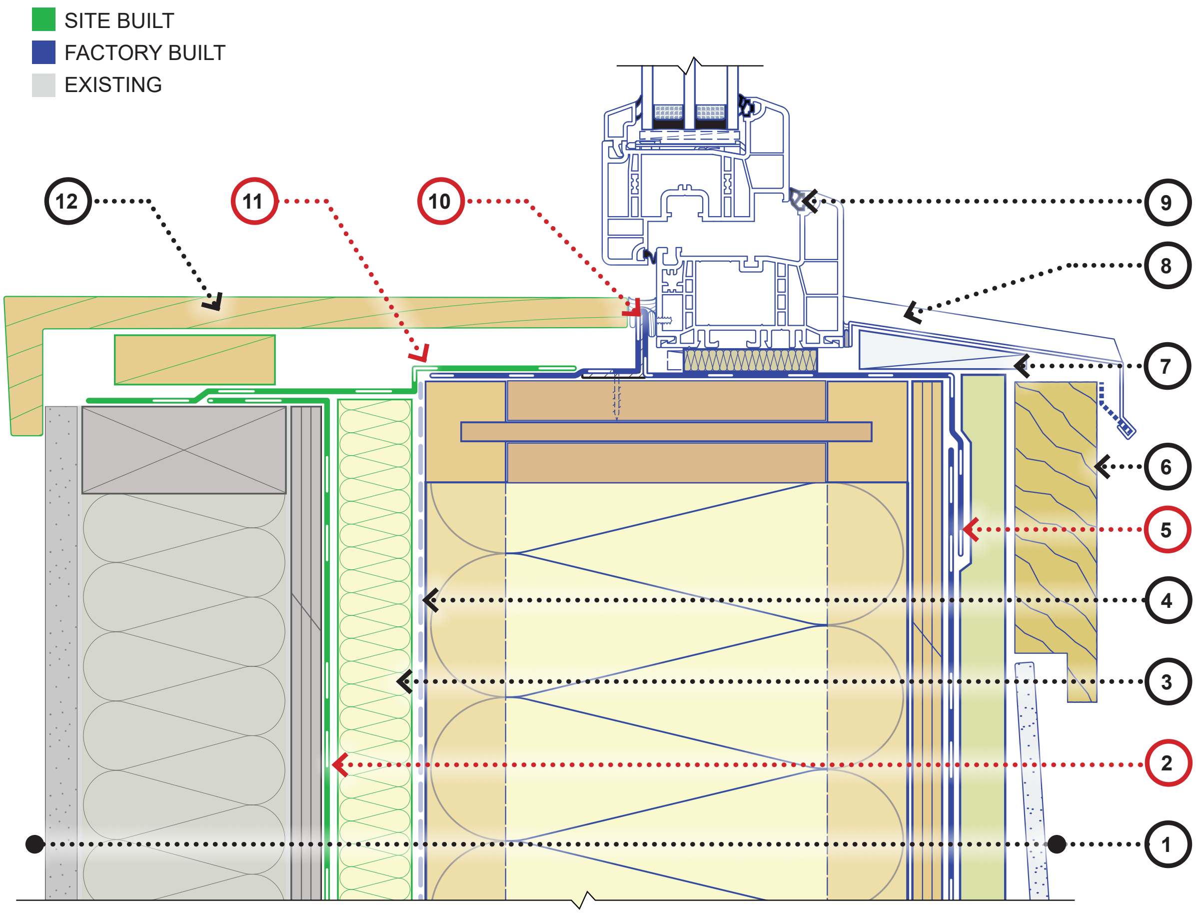


LEGEND

1. I-Joist Framed Panel Wall Assembly.
2. Self-adhered VP membrane adhered to existing sheathing. (AB)
3. Compressible mineral fibre gap fill insulation.
4. Retaining mesh for batt insulation.
5. Intermittent lifting strap secured to plywood plumb shim.
6. Site-applied trim at top of wall.
7. Panel secured fasteners toe-nailed into plywood plumb shim.
8. High performance tape sealed to factory installed self-adhered membrane and roof assembly membrane. (AB/ WRB)
9. Plywood plumb shim fastened at cut back existing roof structure (chainsaw retrofit).
10. Chainsaw retrofit roof assembly.

Detail A.4–04 | Top of Wall

PEER Wall A.4 — I-Joist Panel

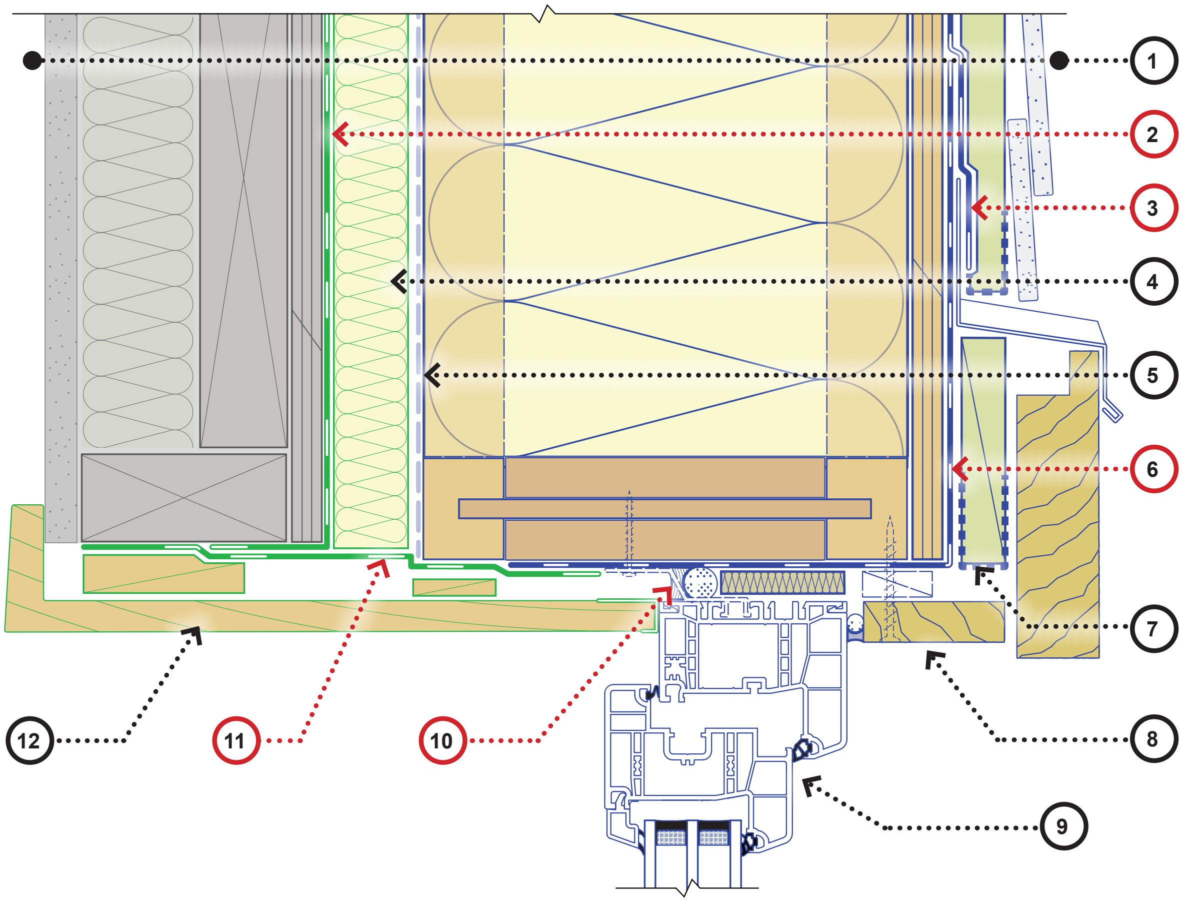


LEGEND

1. I-Joist Framed Panel Wall Assembly.
2. Self-adhered VP membrane adhered to existing sheathing. (AB)
3. Compressible mineral fibre gap fill insulation.
4. Retaining mesh for batt insulation.
5. Self-adhered sill membrane over sill angle and lapped onto field membrane. (AB/WRB)
6. Closure cladding and trim around window.
7. Intermittent angled foam block to support sill flashing.
8. Factory installed window sill flashing.
9. Factory installed new triple-glazed window secured in place with sill angle at sill.
10. Window set into continuous sealant over sill angle and secured with screws. (AB/WRB)
11. Self-adhered VP transition membrane lapped over sheathing membrane and onto sill membrane. (AB)
12. Interior window trim and closure sealant over sill angle as required.

Detail A.4–05 | Window Sill

PEER Wall A.4 — I-Joist Panel



SITE BUILT
FACTORY BUILT
EXISTING

LEGEND

1. I-Joist Framed Panel Wall Assembly.
2. Self-adhered VP membrane adhered to existing sheathing and lapped onto sill membrane. (AB)
3. Self-adhered membrane over head flashing and lapped over head flashing membrane. (WRB)
4. Compressible mineral fibre gap fill insulation.
5. Retaining mesh for batt insulation.
6. VP head flashing membrane. (WRB)
7. Factory installed window head prestrip and strapping.
8. Head trim fastened to top plate.
9. Factory installed new triple-glazed window secured in place with clips at head and jambs.
10. Continuous sealant installed between rough-opening and window head/jambs. (AB/WRB)
11. Self-adhered VP transition membrane lapped over sheathing membrane and onto head flashing membrane. (AB)
12. Interior window trim and closure sealant as required.

Detail A.4–06 | Window Head

PEER Wall A.4 — I-Joist Panel

A.5 PEER Wall — Exterior Insulated Finished System Panel

EIFS wall for prefabricated exterior energy retrofit

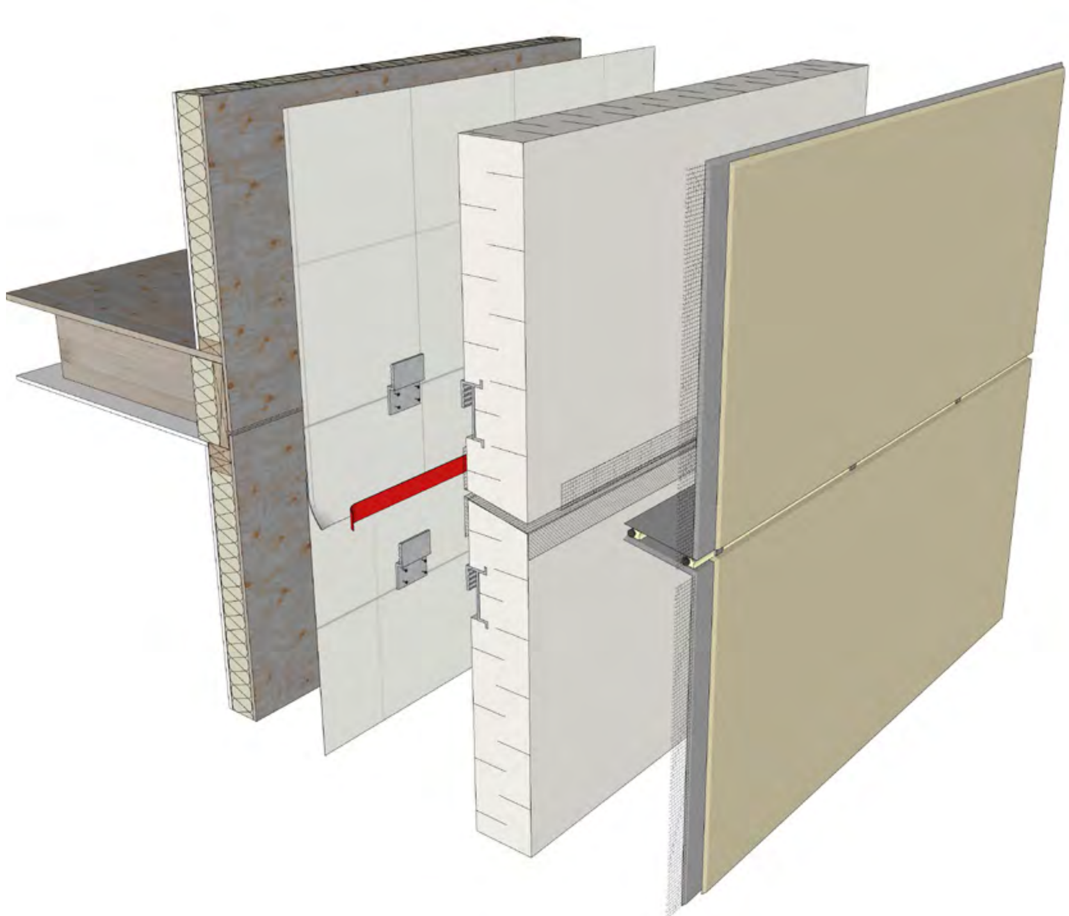


Figure 1 Exploded view of partial retrofit panel components at floor line transition

Developed by Natural Resources Canada's
Prefabricated Exterior Energy Retrofit (PEER) team

A.5 PEER Wall — EIFS Enclosure Assembly Overview

The following is a description of the retrofit panel layers installed on the exterior of the existing house. See also the Typical Construction Details on page 55.

Exterior

- Finish coat
- Base coat with reinforcing mesh
- EPS board insulation
- Air barrier membrane + water resistive barrier
- Existing assembly (not shown)

Interior

Figure 2 Retrofit EIFS wall panel overview (green highlights indicate site-applied perimeter joint/tie-in components)

Retrofit Description

- The Exterior Insulated Finished System (EIFS) panel is provided by Dryvit (Fedderlite M system) or similar panelized EIFS system. The panel is comprised of EPS insulation board with a reinforced base coat and a textured finish coat. The back of the panels have continuous aluminum receiver channels set into the EPS with hotwire.
- The EIFS panels are attached to the existing wall assembly through a cleat system. The EIFS channels clip onto intermittent cleats fastened to the existing backup wall.
- Joints are sealed with drained two-stage joints between the panels and a single-stage joint at the bottom-of-wall. The weather resistive barrier (WRB/AB) must be site installed and is a mechanically fastened sheathing membrane installed on the backup wall.
- The panels are installed over a small drained/unvented cavity behind the EIFS panels.
- New windows must be site installed into the old wall as the EIFS panels are non-load bearing. Air barrier and water resistive barrier transitions at window interfaces and sill flashing must also be site installed.

Potential Benefits of an EIFS Panel Retrofit

- All work (except window installation and interior window trim) is done from the exterior leaving the home livable during construction.
- Site installation work is limited, reducing installation times and disruption to residents.
- Eliminates on-site framing and uses panels to simplify installation.
- Insulation thickness can be varied to accommodate energy performance goals and lot-line setbacks.
- Provides a layer of continuous insulation reducing thermal bridging through framing.
- Increases air tightness, reduces drafts and noise, and lowers energy costs.
- Reduces potential for moisture ingress with careful detailing.
- Provides opportunity for seismic upgrades to meet regional requirements.
- Allows for quality assurance of the air barrier system transitions on site prior to installing EIFS panels.

Key Considerations

Air sealing: The air barrier (AB) is provided by the new sheathing membrane on the existing wall. Flexible membrane around windows, doors, and other penetrations and transitions complete the AB. Sealing at the top plate and base-of-wall where the new sheathing membrane connects to the existing house is also required. Openings around electrical, mechanical, and other service penetrations are sealed throughout the construction process. These are critical details to ensure an airtight barrier.

Connection to existing structure: This retrofit uses a cleat attachment system. A series of channels embedded into the back of the EIFS panels clip onto intermittent wall cleats that are fastened to the existing wall. New windows are site installed into the existing wall frame as the panels are not load bearing.

Water control: A mechanically fastened sheathing membrane is provided at the backup wall as the primary water control and water resistive barrier (WRB). The panels joints are two-stage drained joints and a small non-vented drainage cavity is also provided between the panels and backup wall.

Cladding: The EIFS panels are a complete cladding system that is fully manufactured off-site. Site installation is limited to windows and doors, the WRB, the cladding attachment system, and completing the air barrier at joints, penetrations, and other interfaces.

Cladding is not highly impact-resistant. Best used in low-traffic areas or for applications second storey and above

Durability: The EIFS panels will have a reduced drying potential dependant on the thickness of the EPS insulation. Applications should be modelled to assess risk.

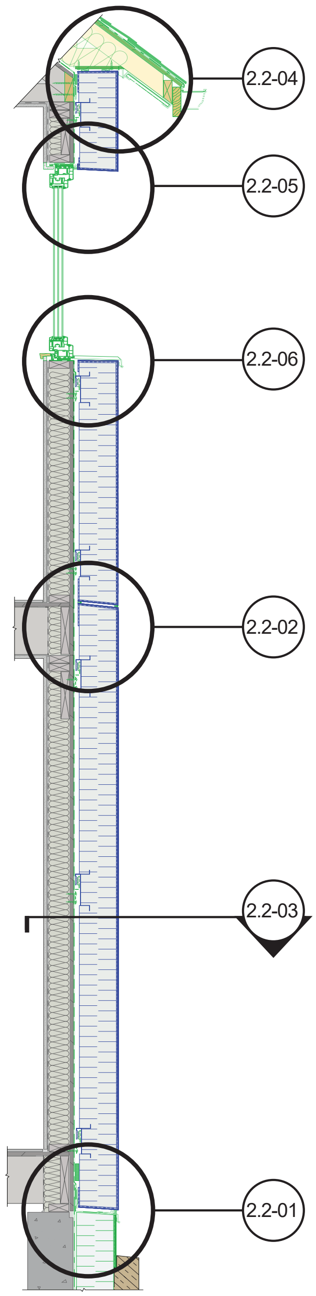


Figure 3 House section detail wayfinder.

Typical Construction Details

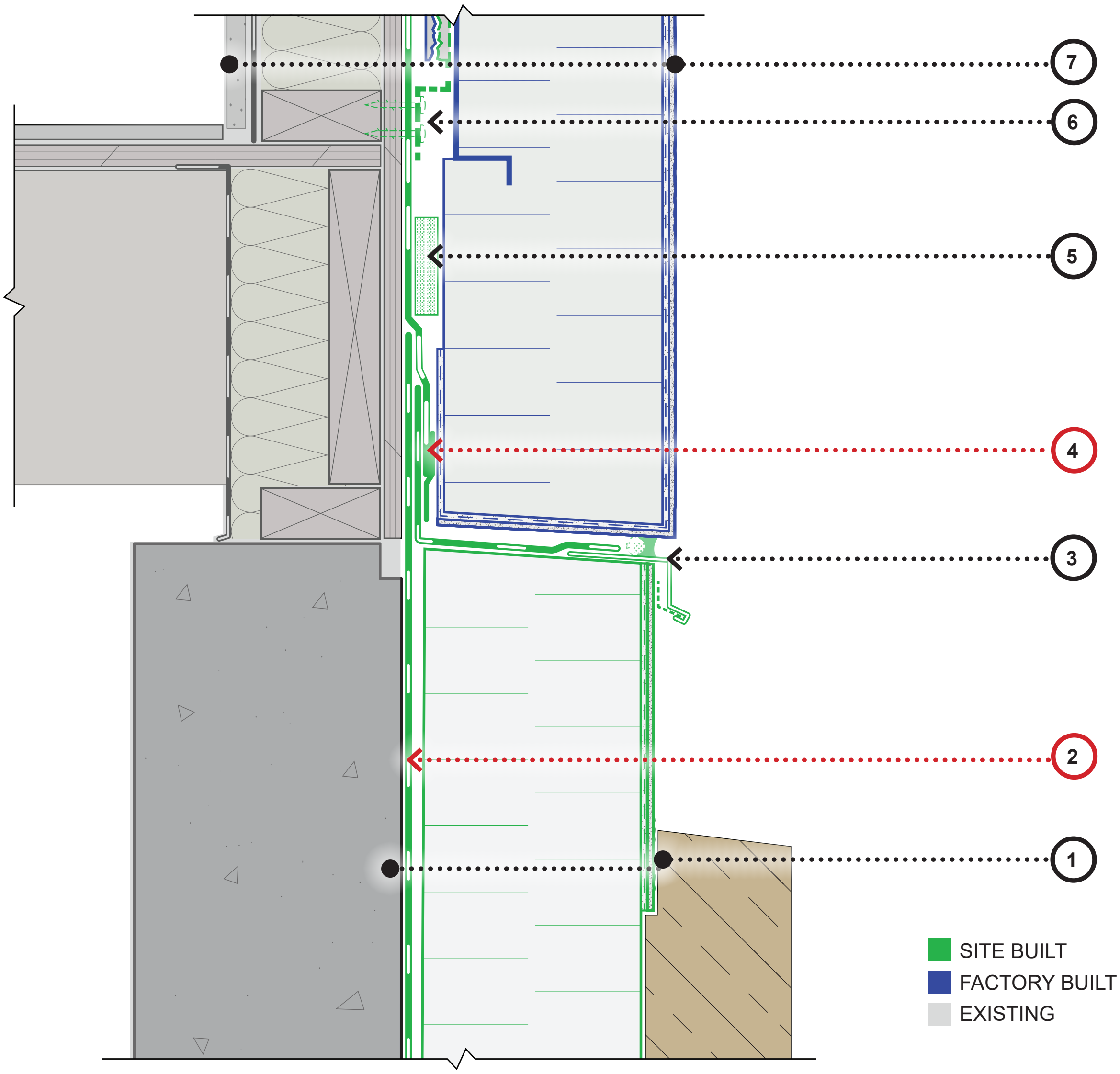
The sample details shown in the following pages are intended to illustrate typical transition approaches both for air barrier and panel/insulation continuity. Note that these are example details, and project-specific details should always be developed to account for the unique conditions of each project.

The annotations and legend in each sample detail contains red “AB” and "AB/WRB" icons to indicate the various air barrier and where applicable water resistive barrier components are present.

Each detail also include a colour legend as follows for the grey, green, and blue components shown:

- SITE BUILT
- FACTORY BUILT
- EXISTING

List of Details

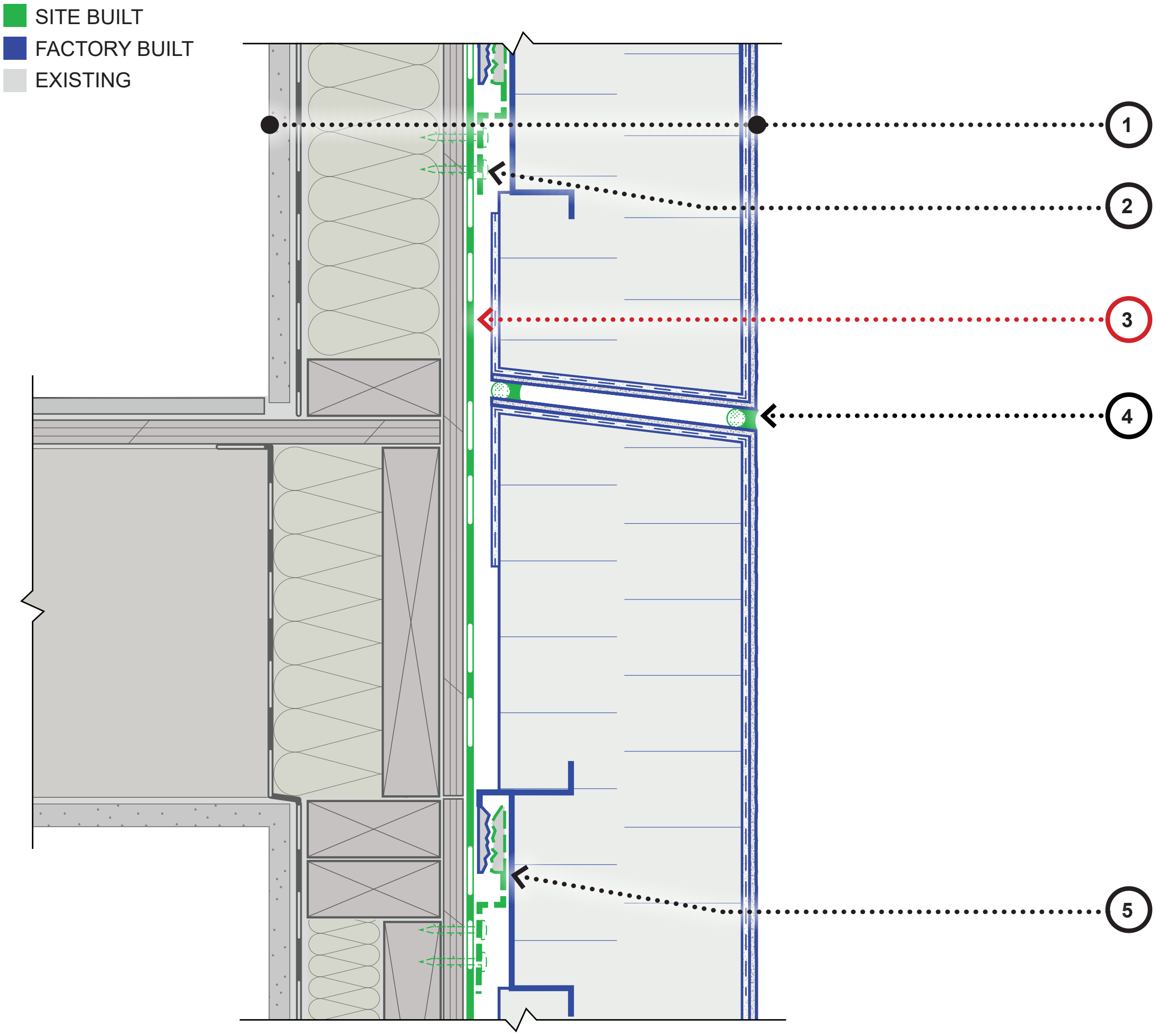


LEGEND

1. Wall Assembly:
   - Parge coat + mesh-reinforced base coat layer
   - EPS foam insulation
   - Self-adhered transition membrane (AB/WRB)
   - Existing assembly
2. Site installed self-adhered transition membrane on foundation wall.
3. Site installed through wall membrane flashing adhered to flashing. Caulking and backer rod with intermittent weep holes.
4. Site installed field membrane lapped onto through wall flashing membrane and tapped at seams. (AB/WRB)
5. Reticulated air foam baffle.
6. EIFS panel clips fastened to existing assembly.
7. EIFS Wall Assembly.

Detail A.5–01 | Base of Wall at Foundation

PEER Wall A.5 — EIFS Panel

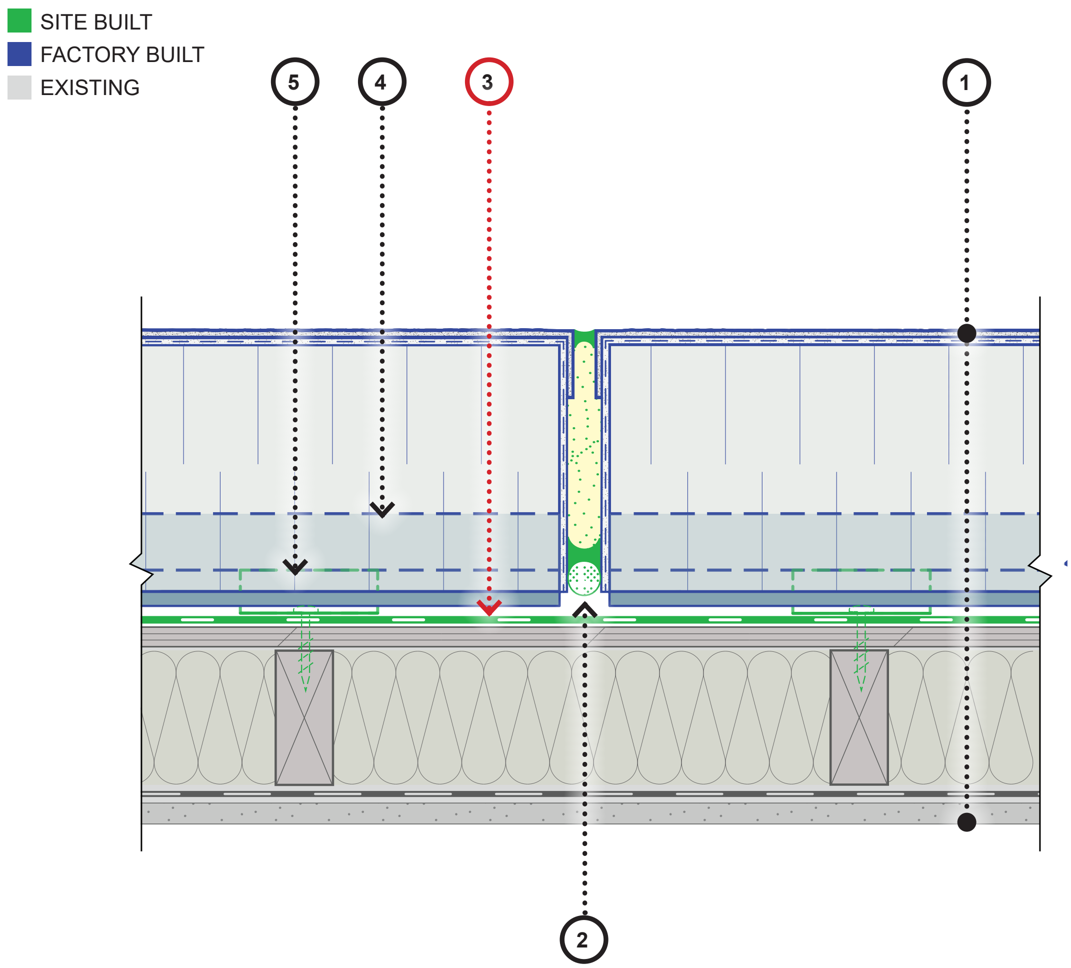


LEGEND

1. EIFS Wall Assembly.
2. EIFS panel clips fastened to existing assembly.
3. Site installed field membrane. (AB/WRB)
4. Two-stage drainage channel with intermittent weeps through caulking.
5. EIFS panel clips fastened to existing assembly.

Detail A.5–02 | Horizontal Panel Joint

PEER Wall A.5 — EIFS Panel

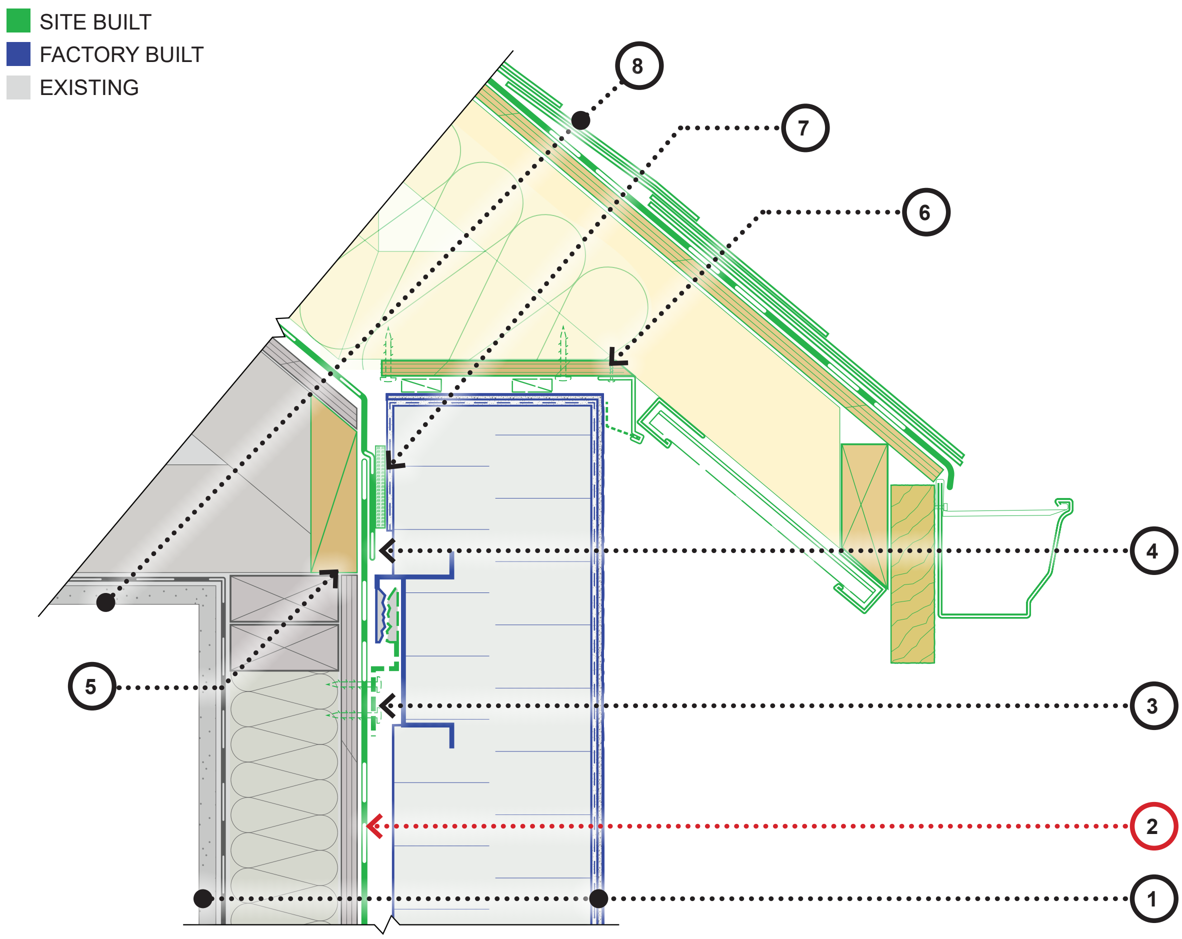


LEGEND

1. EIFS Wall Assembly.
2. Self expanding foam joint sealant used as backer for caulking at exterior side. Backer rod used at interior side.
3. Site installed field membrane. (AB/WRB)
4. EIFS clip channel secured to site installed clips.
5. Site installed clips fastened to existing assembly.

Detail A.5–03 | Vertical Panel Joint

PEER Wall A.5 — EIFS Panel

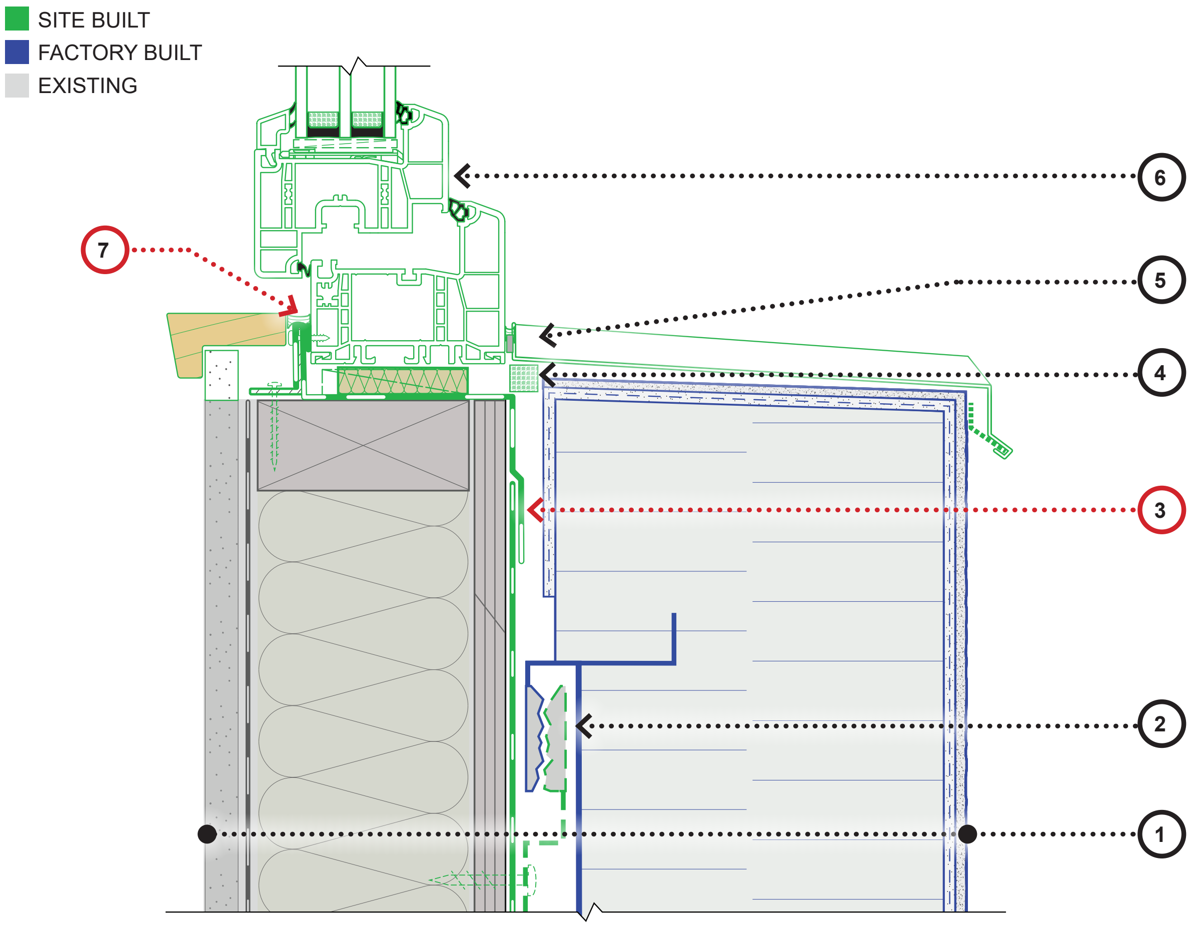


LEGEND

1. EIFS Wall Assembly.
2. Site installed field membrane. (AB/WRB)(AB/WRB)
3. EIFS panel clips fastened to existing assembly.
4. Roof membrane lapped onto fastened field membrane and taped at seams. (AB/WRB)
5. Site installed wood blocking to receive roofing membrane.
6. Plywood shim fastened to site installed roof structure to provide clearance for vented space behind EIFS panel.
7. Reticulated air foam baffle.
8. Chainsaw retrofit roof assembly.

Detail A.5–04 | Top of Wall

PEER Wall A.5 — EIFS Panel

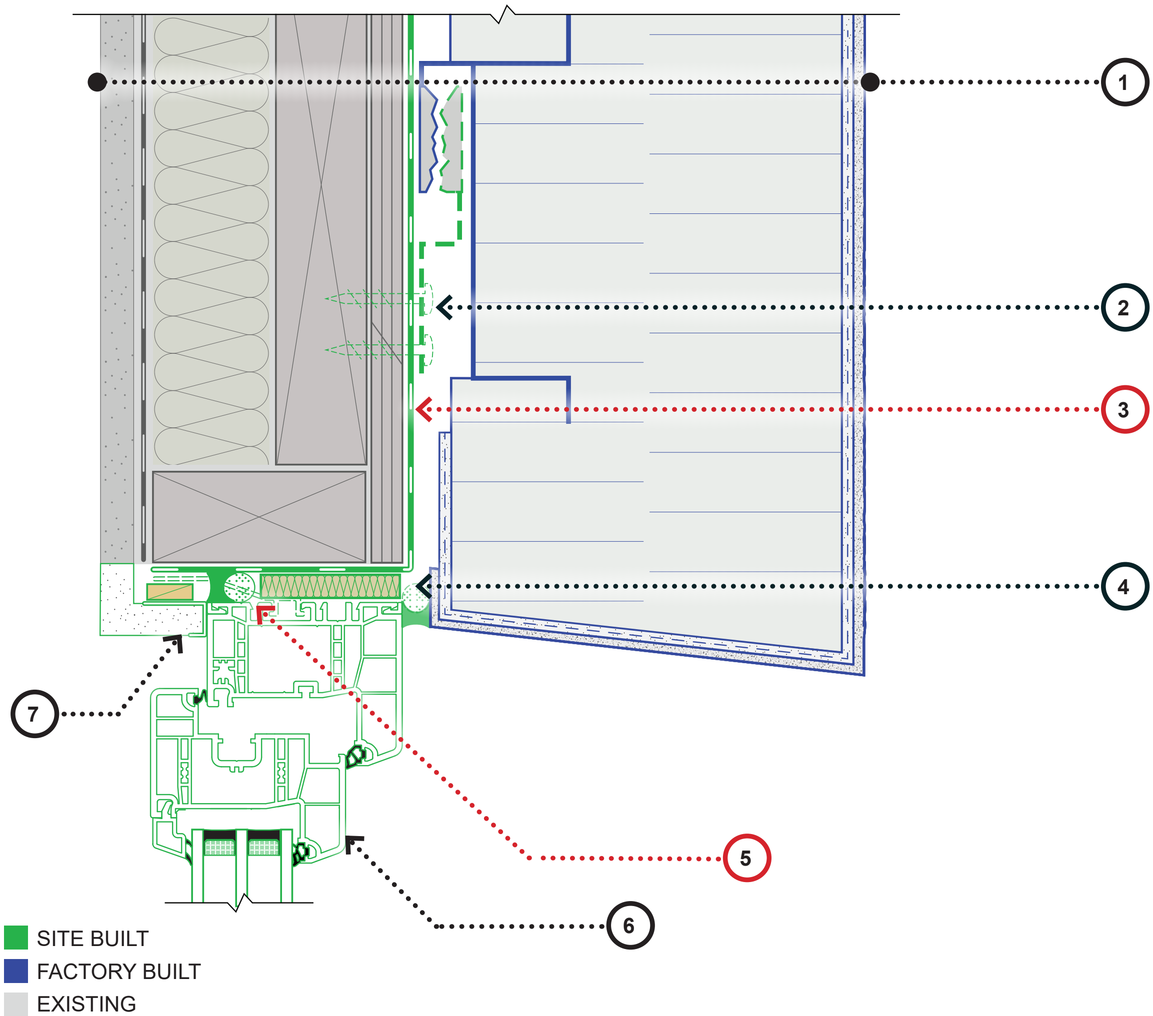


LEGEND

1. EIFS Wall Assembly.
2. EIFS panel clips fastened to existing assembly.
3. Site installed self-adhered sill membrane over sill angle and lapped onto field membrane. Membrane transition seems taped. (AB/WRB)
4. Reticulated air foam baffle.
5. Window sill flashing clipped to sill trim with perforated metal receiver and adhered to face of window frame with foam tape and sealant.
6. Site installed new triple-glazed window secured in place with sill angle at sill.
7. Site installed window set into continuous sealant over sill angle and secured with screws. (AB/WRB)

Detail A.5–05 | Window Sill

PEER Wall A.5 — EIFS Panel



LEGEND

1. EIFS Wall Assembly.
2. EIFS panel clips fastened to existing assembly.
3. Site installed field membrane lapped onto existing assembly. (AB/WRB)
4. Site installed backer rod and caulking with intermittent weeps between new window and EIFS panel.
5. Continuous sealant installed between rough-opening and window head/jambs. (AB/WRB)
6. Site installed new triple-glazed window secured in place with clips at head and jambs.
7. Interior gypsum.

Detail A.5–06 | Window Head

PEER Wall A.5 — EIFS Panel

APPENDIX B: PEER PANEL CLEAR FIELD R-VALUES, EMBODIED CARBON, AND WEIGHT LOOK-UP TABLES

Summary: Table B-1 summarizes the clear field R-value, embodied carbon, and mass for various permutations of PEER panel prototypes.

Scope: Is limited to the wall panel construction itself. Rainscreen strapping included but cladding excluded. Existing building's back-up wall excluded. Demolition excluded. Other building envelope components (roof, foundation, fenestration) also excluded.

Method: Material takeoffs for a typical 26x9' (234ft^2 or 21.74m^2) panel were assumed. Associated emissions estimated with the NRCan Material Emission Calculator (V1.0). These were then normalized on a ft2 (m^2) basis. Clear Field Thermal Resistance was calculated using the Isothermal Planes method[3].

3 2021 ASHRAE Handbook—Fundamentals—Chapter 25 (F25.8), American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc., Atlanta, GA.

Panel System	Sheathing	Panel Thickness		Clear Field R-value (Isothermal planes)		Specific Net Carbon Footprint		Specific Mass	
		(in)	(mm)	(RIP)	(RSI)	(kg CO_2e / ft²)	(kg CO_2e / m²)	(lb/ft²)	(kg/m²)
2x4 Wood-frame Standoff Panel @ 16" OC w/ 2" standoff insulated with dense-pack cellulose	1/2" OSB	6 3/4	171.5	20.7	3.65	0	-3	4.97	24.28
2x4 Wood-frame Standoff Panel @ 24" OC w/ 2" standoff insulated with dense-pack cellulose	1/2" OSB	6 3/4	171.5	21.1	3.72	0	-3	4.76	23.23
2x4 Wood-frame Standoff Panel @ 24" OC w/ 4" standof insulated with dense-pack cellulose	1/2" OSB	8 3/4	222.3	28.0	4.92	-1	-6	5.56	27.14
2x4 Wood-frame Standoff Panel @ 16" OC w/ 4" standoff insulated with dense-pack cellulose	1/2" OSB	8 3/4	222.3	28.3	4.99	-1	-6	5.34	26.08
Structural Insulated Panel (5 1/2" EPS-I)	1/2" OSB (x2)	8 1/4	209.6	25.6	4.51	2	21	4.43	21.63
Structural Insulated Panel (5 1/2" Neopore GPS-I)	1/2" OSB (x2)	8 1/4	209.6	31.0	5.47	1	15	4.43	21.63
Structural Insulated Panel (7 1/4" EPS-I)	1/2" OSB (x2)	10	254.0	32.1	5.65	2	25	4.64	22.64
Structural Insulated Panel (7 1/4" Neopore GPS-I)	1/2" OSB (x2)	10	254.0	39.3	6.92	2	17	4.64	22.64
Structural Insulated Panel (9 1/4" EPS-I)	1/2" OSB (x2)	12	304.8	39.5	6.96	3	31	4.89	23.87
Structural Insulated Panel (9 1/4" Neopore GPS-I)	1/2" OSB (x2)	12	304.8	48.7	8.58	2	21	4.89	23.87
Nailbase (5-1/2" EPS-II)	3/4" OSB	8	203.2	24.8	4.38	2	21	3.35	16.37
Nailbase (5-1/2" Neopore GPS-II)	3/4" OSB	8	203.2	30.9	5.44	2	19	3.35	16.37

Panel System	Sheathing	Panel Thickness		Clear Field R-value (Isothermal planes)		Specific Net Carbon Footprint		Specific Mass	
		(in)	(mm)	(RIP)	(RSI)	(kg CO_2e / ft²)	(kg CO_2e / m²)	(lb/ft²)	(kg/m²)
Nailbase (7-1/4" EPS-II)	3/4" OSB	9 3/4	247.7	32.9	5.79	2	25	3.35	16.37
Nailbase (7-1/4" Neopore GPS-II)	3/4" OSB	9 3/4	247.7	39.1	6.89	2	23	3.35	16.37
I-Joist Panel (9-1/2" TJIs @ 16"OC c/w R-3.7/in cellulose)	1/2" OSB (x2)	12 1/4	311.2	29.5	5.19	0	-5	10.42	50.86
I-Joist Panel (9-1/2" TJIs @ 24"OC c/w R-3.7/in cellulose)	1/2" OSB (x2)	12 1/4	311.2	30.5	5.37	0	-5	9.83	48.01
I-Joist Panel (9-1/2" TJIs @ 16"OC c/w R-4.0/in mineral wool)	1/2" Gypsum	11 3/4	298.5	29.8	5.26	3	33	8.52	41.62
I-Joist Panel (9-1/2" TJIs @ 24"OC c/w R-4.0/in mineral wool)	1/2" Gypsum	11 3/4	298.5	31.0	5.46	3	32	7.91	38.62
I-Joist Panel (9-1/2" TJIs @ 16"OC c/w R-3.6/in fibreglass batt)	1/2" OSB	11 3/4	298.5	28.5	5.02	1	8	7.16	34.95
I-Joist Panel (9-1/2" TJIs @ 24"OC c/w R-3.6/in fibreglass batt)	1/2" OSB	11 3/4	298.5	29.5	5.19	1	7	6.51	31.76
I-Joist Panel (9-1/2" TJIs @ 16"OC c/w Hemp fiber batt / R 3.7/inch	1/2" OSB	11 3/4	298.5	28.8	5.08	0	1	7.96	38.88
I-Joist Panel (9-1/2" TJIs @ 24"OC c/w Hemp fiber batt / R 3.7/inch	1/2" OSB	11 3/4	298.5	29.9	5.26	0	0	7.34	35.85
I-Joist Panel (9-1/2" TJIs @ 16"OC c/w Straw Bale / R 3.3/inch	1/2" OSB	11 3/4	298.5	27.4	4.82	-3	-30	10.63	51.87
I-Joist Panel (9-1/2" TJIs @ 24"OC c/w Straw Bale / R 3.3/inch	1/2" OSB	11 3/4	298.5	28.2	4.97	-3	-31	10.11	49.34

Table B-1: Clear field R-value, estimated embodied carbon and mass of various variations of PEER panel designs

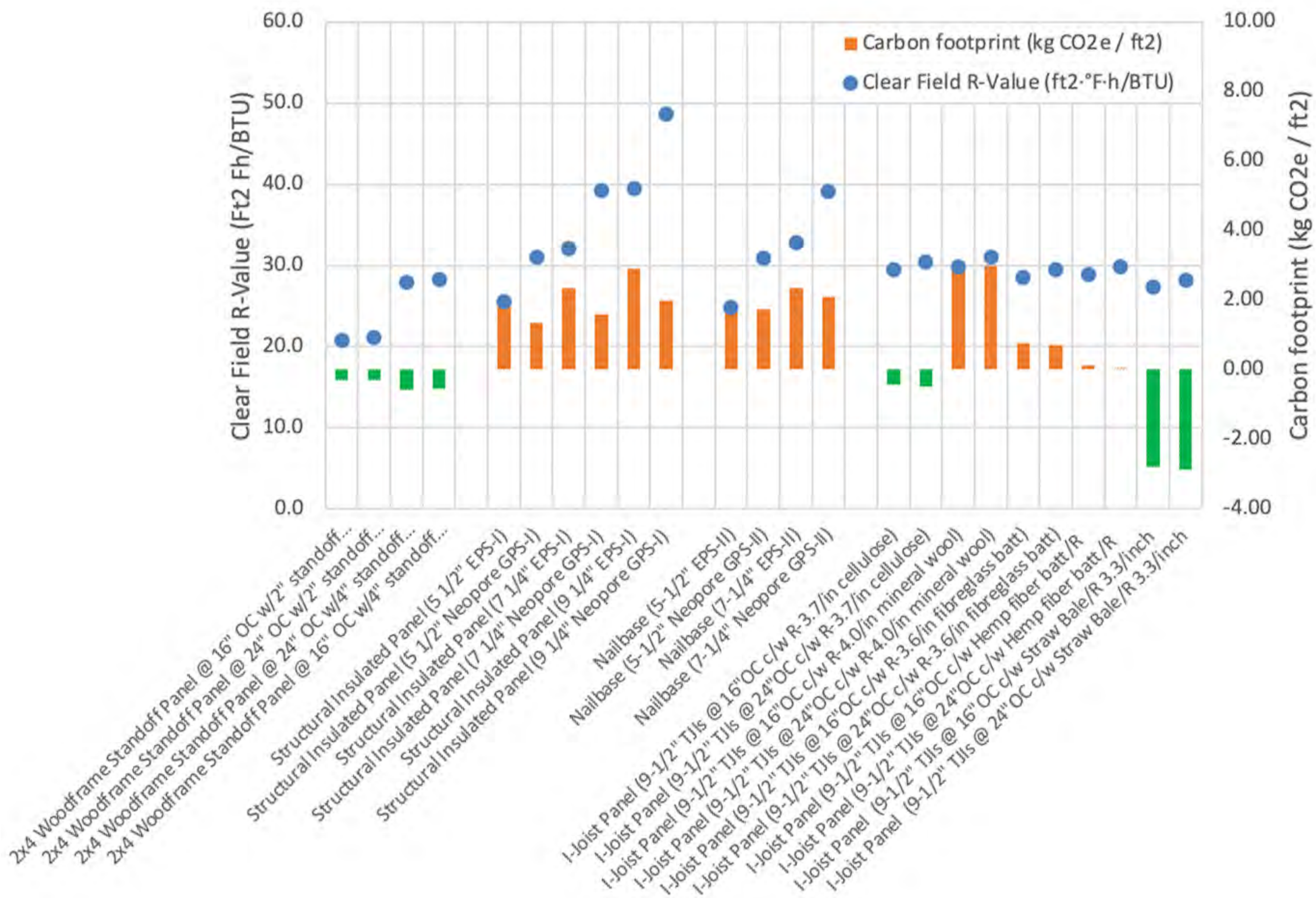


Figure B-1: Estimated clear Field R-value and embodied carbon content of variations of the PEER panels described in Appendix A. The blue dots represent the R-value, orange bars represent embodied carbon content per ft^2, green bars represent panels that are net-carbon storing. Note–cladding omitted from R-value and embodied carbon estimates.

APPENDIX C: CANADIAN HOUSING STOCK CHARACTERISTICS

The following plots present the typical thermal characteristics of the Canadian housing stock by vintage, and by province or territory. The data is taken from energy evaluations performed on low-rise housing through Canada's national home energy rating system, the EnerGuide Rating System (ERS). The ERS dataset represents approximately 5% of the Canadian housing stock and gives insight into the current performance of the stock.

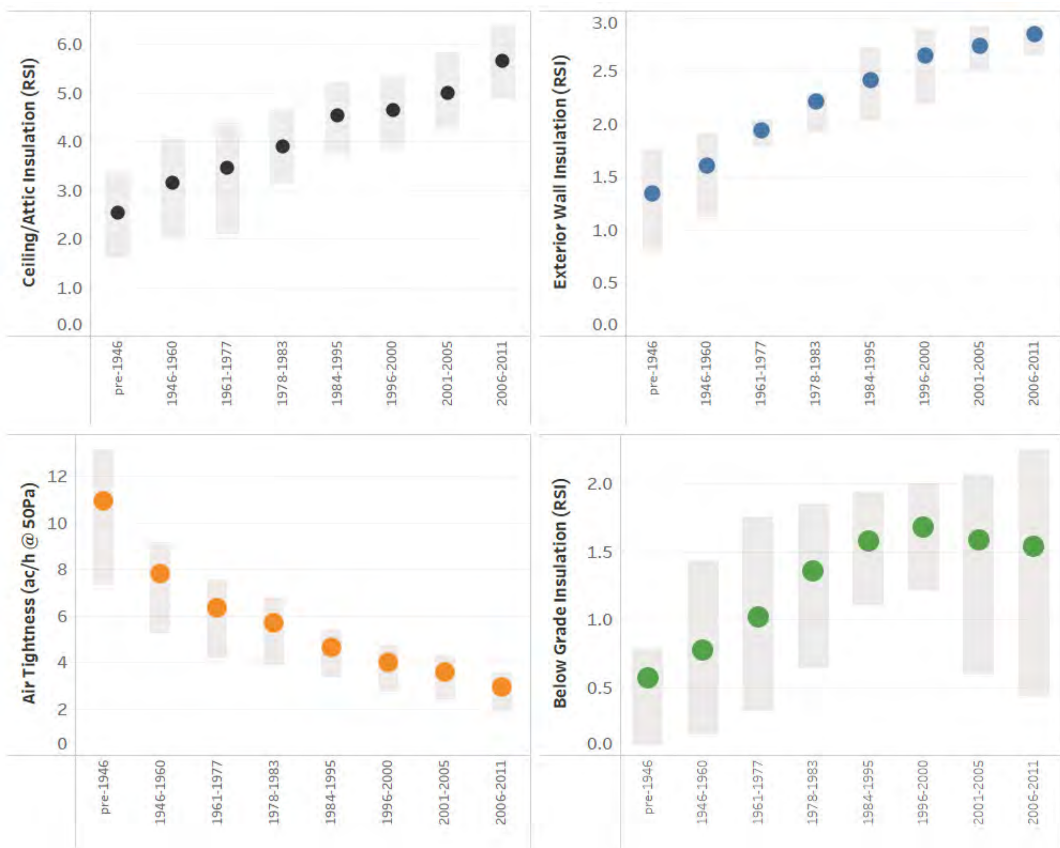


Figure C.1: Thermal characteristics of Canadian housing by vintage

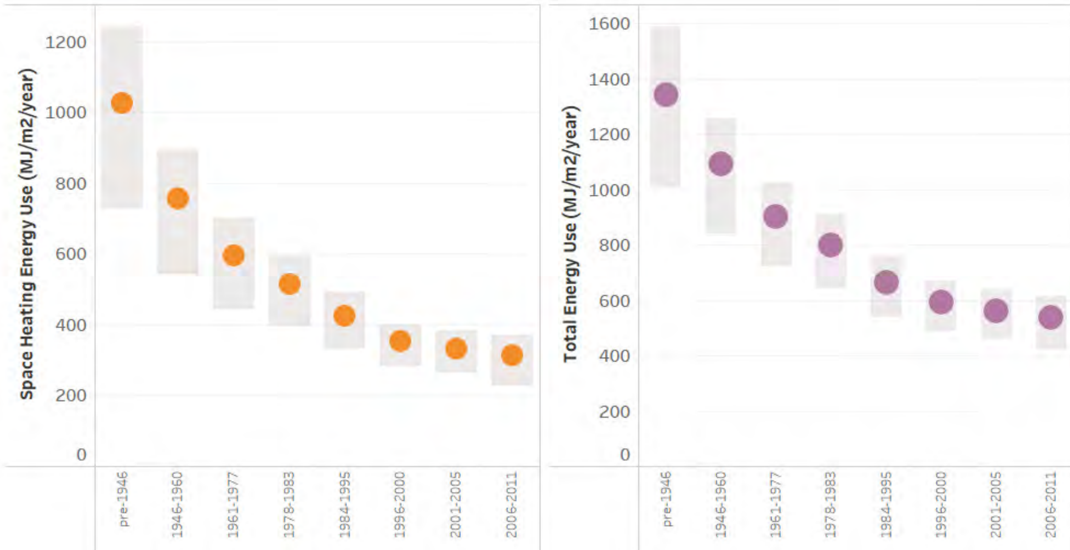


Figure C.2: Space heating and total energy use by vintage

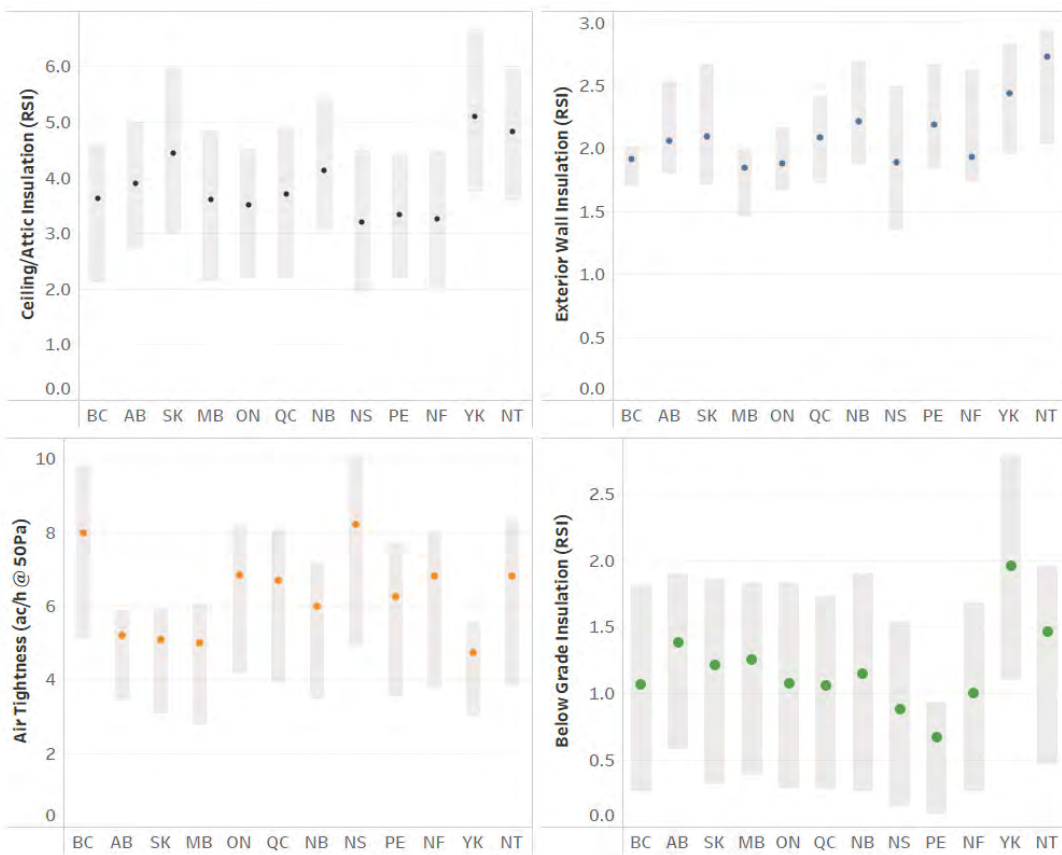


Figure C.3: Thermal characteristics by province or territory

APPENDIX D: SAMPLE TENANT COMMUNICATIONS

The PEER Project—renovating the outside of your home to reduce your energy costs and improve your comfort

The building your home is in has been identified as a (potential) location for an exciting prefabricated exterior energy retrofit (PEER) transformation. This information sheet tells you what you need to know about the project.

What is a prefabricated exterior energy retrofit?

The building enclosure is a term used to describe all the elements of a house that keep the heat in and the weather out. The enclosure consists of the walls, windows, doors, roof, and foundation. Older homes tend to have poorly insulated and leaky enclosures. This contributes to high heating bills, poor comfort, and risk of condensation, which can lead to mould.

A prefabricated exterior energy retrofit consists of wrapping the whole house in a new enclosure. This will consist of factory-built, insulated panels that include new windows and doors, custom built to attach to the exterior of the building. The panels will be lifted into place using a crane. This ensures that the whole project is quickly completed with minimal disruption. Some additional work will be done to remove existing windows and doors and make sure that there is proper ventilation (exchange of air from inside the house to the outside to promote good indoor air quality).

How will this benefit me?

- **You can continue to live in your home normally when this work is being done**. With minimal disruption.
- **You will save on utility bills.** The new building enclosure (walls, windows, doors and roof) will significantly reduce heat loss and drafts from your home. This will save money on your heating bill.
- **You will be more comfortable.** After the renovation your home will be less drafty and will have better indoor air quality.
- **You will be helping the environment by contributing less to climate change.** The new walls will mean that you're using less energy to heat your home.
- **Your home will look better.** The renovation will give the house a "facelift" and modernize its appearance.

What should tenants expect?

During [timeframe], the building will be measured and its condition will be assessed.

- Field technicians will be in the area for 1–2 days taking building measurements from the outside using surveying instruments
- The survey equipment will include laser technology (LiDAR—Light, Imaging, Detection, and Ranging) and cameras. LiDAR measures the distance to surrounding objects by sending out laser pulses and measuring return time of reflected light. Infrared cameras will be used to capture heat signatures to identify where heat is leaking from your home.

Figure: LiDAR Scanner and Infrared Camera

- These technicians will be setting up their equipment in various locations around the building (including front and rear yards). Each measurement scan can take anywhere from 10–20 minutes.
- The data will be used to take precise measurements to design and custom build panels that will be installed on the exterior of your home.

On [insert date], a technician is coming to do **a blower door test** to measure how much air leaks from your home, and other aspects of your home’s energy performance, such as type of furnace and amount of insulation in the walls. For this test, the technician will need access to the inside of your home for a few hours.

After the scans and tests, the team will take the information collected to evaluate the feasibility of the project and potentially design and build the panels. We will notify you again to share when in-site construction is expected to start. When it does, it should only last a few weeks.

What do I have to do?

To help this project we would like you to answer a few questions about your comfort level in your home and energy use habits. We will also ask for your consent to access your natural gas and electricity bills for the past two years. This will help us predict and measure the energy and cost savings from the renovation. A representative will follow up with specific questions and a consent form.

Because the majority of this work will be done from the outside, there will be minimal disruption to you. You will not, for example, have to move out or be away from your home for any period of time.

Let us know if you have any questions or concerns

For more information,

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About CanmetENERGY

Natural Resources Canada's CanmetENERGY is the Canadian leader in clean energy research and technology development. Our experts work in the fields of clean energy supply from fossil fuel and renewable sources, energy management and distribution systems, and advanced end-use technologies and processes. Ensuring that Canada is at the leading edge of clean energy technologies, we are improving the quality of life of Canadians by creating a sustainable resource advantage.

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