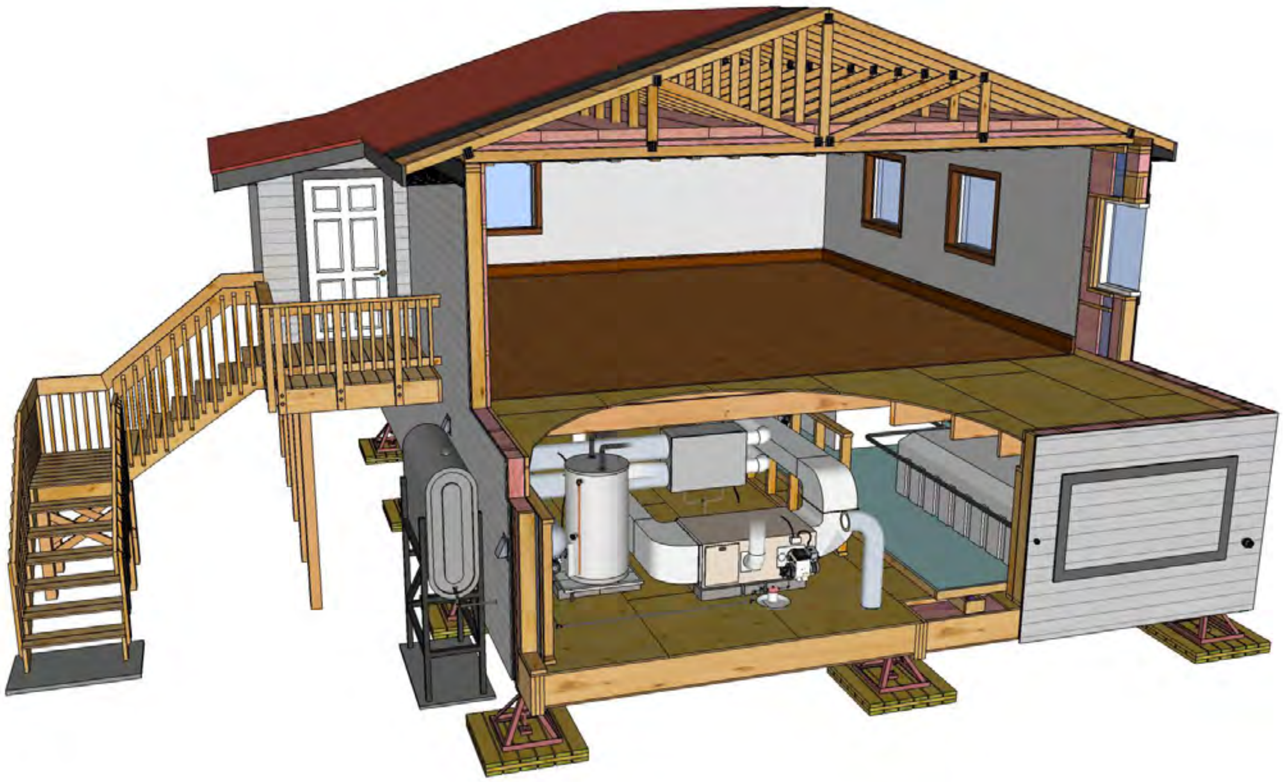
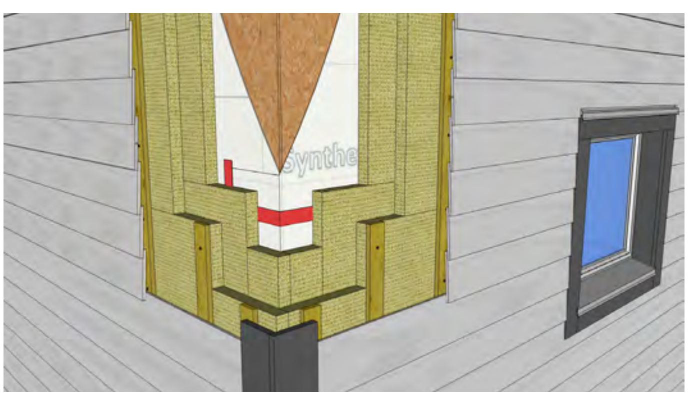
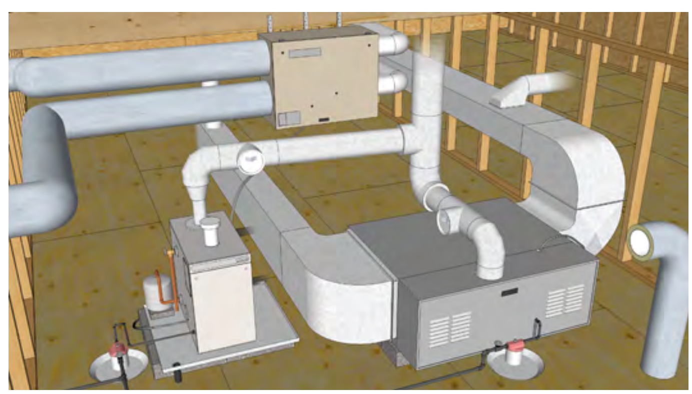
Illustrated Guide for Northern Housing Retrofits







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1.0 Introduction - How to Use this Guide

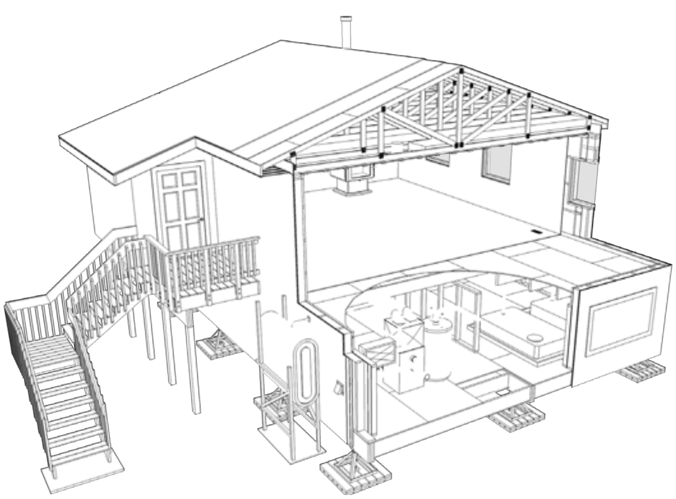
The "Illustrated Guide for Northern Housing Energy Retrofits" covers two optimal retrofit programs for a typical single-family dwelling in Canada's far North (1. Cost-effective, 2. Energy-optimal). The guide is intended to be an industry resource for achieving higher energy efficiency in existing homes, while maximizing utility cost savings and home passive survivability through lower energy use.

House as a System

Houses are complex systems that operate based on the interaction of various components with occupants and the exterior environment. When considering modifying any one component of a building it is important to also consider the interaction of that component with other building elements. For example, improved airtightness may require changes to existing ventilation systems and passive air inlets and better insulated enclosure assemblies may allow the sizing of the heating system to be reduced. In considering an energy retrofit project, it is important to consider how building systems interact; specifically, the building enclosure and mechanical heating, ventilation, and air conditioning systems (HVAC).

The following list highlights how different energy retrofits will impact different systems and homeowner comfort and use of the home:

- Air sealing work makes a home less drafty and more comfortable, and can reduce space conditioning costs.
- In some situations, an air sealing retrofit without consideration for make-up air can depressurize the building enclosure, leading to unsealed combustion appliances (oil furnaces, wood stoves, etc.) backdrafting and potentially spilling carbon monoxide and other harmful combustion gases into the home.
- Adding insulation can reduce space conditioning costs and make indoor spaces more comfortable and interior surfaces less prone to condensation and subsequent deterioration.
- Adding insulation to walls, roofs, and floors could potentially lead to condensation in concealed spaces if vapour diffusion and air leakage control is not properly addressed, or incorrect materials are used.
- Adding insulation and sealant materials to a tightly air-sealed home can reduce indoor air quality if specified products contain harmful chemicals such as volatile organic compounds (VOCs) and are not properly managed during installation. Furthermore, chemicals in new furnishings (furniture, curtains, etc.) may also contribute to poor indoor air quality if not managed appropriately after an air sealing retrofit is completed.



All the parts of the house including its contents and occupants interact to form an integrated system — this is important to understand when performing air sealing and insulation work. This guide covers air sealing and insulation weatherization work for all parts of the house.

Building Enclosure

The building enclosure separates indoor from outdoor space. The enclosure includes assemblies such as the foundations, exposed floors, above grade walls, roofs and attic spaces, and windows and doors. These assemblies are designed to manage water (rain, snow, ground and melt water), water vapour, air movement, and heat loss-gain. Increasing building airtightness and insulation levels can improve energy performance, occupant comfort, and building longevity.

Mechanical Heating, Ventilation, and Air Conditioning (HVAC)

A variety of components are associated with the HVAC system, including: wood/pellet stove, heat recovery ventilator, hot water tank, bathroom and kitchen exhaust vents, and forced-air oil furnace.

Ventilation is the process of supplying air to, or removing air from, a space for the purpose of controlling air contaminant levels, humidity, and temperature within the space. It is an important contributor to the healthiness and comfort of an indoor environment. Mechanical ventilation is the intentional movement of air into and out of a building using fans and associated ductwork, grilles, diffusers, and other penetrations. Generally, a balanced ventilation system is desired where one fan is used to bring outside air into the building and another fan is used to exhaust roughly the same amount of stale interior air. Heat recovery ventilators (HRVs) are an efficient way to maintain a balanced system with adequate ventilation levels as building air tightness increases and, correspondingly, mechanical ventilation becomes more important.

The space heating system is responsible for generating warmth within the building. The generation and distribution of heat has a significant impact on home thermal comfort and energy performance. Heat can be generated by combusting solid, liquid, or gaseous fuels or, alternatively, by transforming electricity into heat (resistance heaters, heat pumps). The heating source generally interacts with the ventilation system in order to transport heat to all areas of the building. However, stand-alone space heaters (wood/pellet stoves, direct vent heaters) are also common in the North and utilized for targeted heating applications.

Water heating is the process by which water is heated above its initial temperature for domestic uses including cooking and cleaning. An energy source (electricity or heating fuel) is utilized for heating cold incoming water and the conditioned water is then distributed to various areas of the building via piping. Improving the energy efficiency of the water heating appliance can have an important impact on the overall building energy performance.

Conflicting demands on the HVAC system (utility cost savings, occupant comfort) can have a subsequent impact on building energy efficiency. While improving ventilation can increase the supply of fresh air within a home, increasing occupant health and comfort, it can also lead to higher utility costs. It is important to acknowledge that building energy performance is not a panacea: other building demands must sometimes be prioritized over energy efficiency improvements.

Example of typical oil-fired mechanical equipment found in Northern houses.

2.0 Understanding the Northern Context

In geographical terms, the North is generally designated as the area contained within the three Canadian territories (Yukon, North West Territories, Nunavut), occasionally including parts of northern Quebec and Labrador. While the region encompasses over a third of Canada, it is sparsely populated and largely undeveloped: limited transportation, waste, and energy infrastructure exists and most communities are isolated from each other and the South. The climate is also severe with temperatures remaining below zero degrees Celsius for much or all of the year. At northern latitudes sea ice and ground permafrost are often present throughout the year. As a result of the above considerations, unique demands are placed on buildings designed and constructed in the North.

Climate

While the North is often thought of as a homogeneous environmental region, it actually encompasses several different climactic zones. Although parts of southern Yukon and the North West Territories contain milder climates, this Guide is primarily interested in the subarctic and arctic climactic zones. The subarctic climate zone is below the tree line and composed of boreal forest whereas the arctic climate zone is mostly above the tree line and made up of barren tundra.

As both arctic and subarctic climates often have annual mean temperatures below freezing, ground permafrost is commonplace. Areas where permafrost coverage is consistent throughout the year are designated as continuous whereas areas where permafrost is present in only parts of the landscape are considered discontinuous. Both continuous and discontinuous permafrost zones require special foundations for building structural support.

This places limitations that would otherwise not exist on many energy retrofits. Material availability should always be confirmed prior to completing energy retrofits in order to ensure that the specified building materials can be obtained.

Logistics

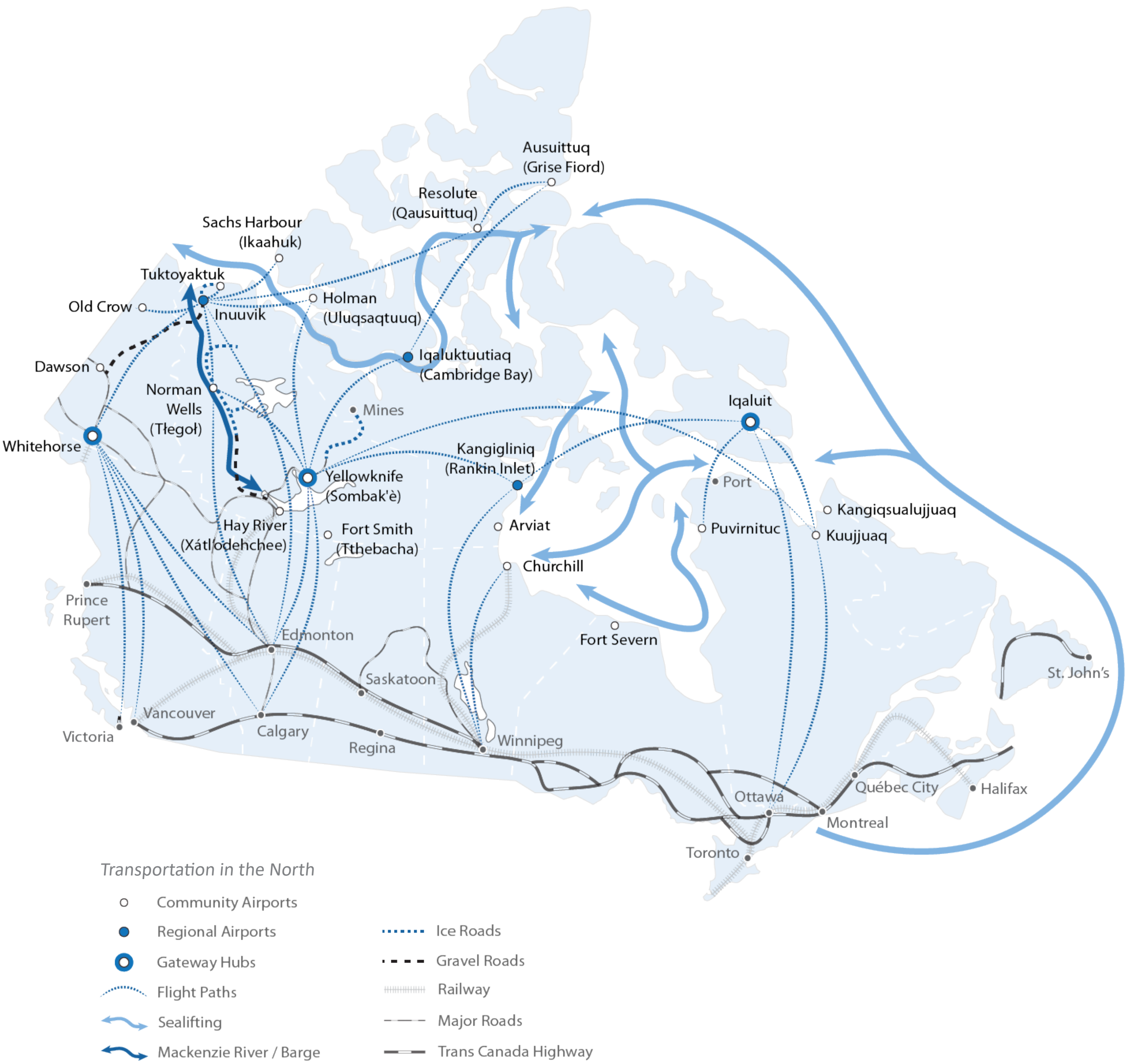
Climate and remoteness have a significant impact on accessibility in many areas of the North. Of particular importance is the transportation networks that allows for the movement of people and goods to and from northern communities. Many towns and smaller communities do not have consistent land access and rely on other transportation modes to receive vital perishable and non-perishable materials. Isolated communities are heavily dependent on important gateway hubs such as Yellowknife as staging points for freight and passengers (see map on the following page).

In general, access to building materials and labour is dependent on the following transportation modes:

1. Sea Lifting and Barges - Large shipping vessels transport heavy goods including construction materials from southern locations to northern coastal settlements when sea ice recedes in the summer. Barges are often needed to transport the goods from the shipping vessels to the land where they can be transported into town. However, it is sometimes possible for large shipping vessels to beach at high-tide with their goods unloaded as the tide recedes. Typically, goods are available by sealifting immediately after the ice thaws in early July until early October (approximately 3 months). Note that sea lift shipping space must be booked several months in advance in order for construction materials to arrive during the shipping season.

2. Flying - Many northern communities are dependent on airports for passenger access and perishable goods. Aerial transportation in the North follows a hierarchy, where local community airports are dependent on regional airports and regional airports are then dependent on gateway hubs such as Yellowknife, Iqaluit, and Whitehorse. Typically, airlifting goods and passengers is possible year round; however, daily flights are only commonplace in June when the weather is milder.

3. Ice Roads - Seasonal ice roads, constructed over frozen lakes and land, allow commercial trucks and other vehicles to travel between northern communities with goods and passengers throughout the winter. Ice roads are generally usable from late December until early April; however, monitoring and maintenance must be performed over this period to ensure the roads function safely.


Ausuittuq
(Grise Fiord)
Resolute
(Qausuittuq)
Sachs Harbour
(Ikaahuk)
Tuktoyaktuk
Old Crow
Inuuvik
Holman
(Uluqsaqtuuq)
Iqaluktuutiaq
(Cambridge Bay)
Dawson
Norman
Wells
(Tłegoł)
Mines
Whitehorse
Iqaluit
Kangigliniq
(Rankin Inlet)
Yellowknife
(Sombak'è)
Port
Kangiqsualujjuaq
Hay River
(Xátł'odehchee)
Fort Smith
(Tthebacha)
Arviat
Puvirnituc
Kuujjuaq
Churchill
Prince
Rupert
Edmonton
Fort Severn
St. John's
Saskatoon
Vancouver
Victoria
Calgary
Regina
Winnipeg
Québec City
Halifax
Ottawa
Montreal
Toronto
Transportation in the North
Community Airports
Regional Airports
Gateway Hubs
Flight Paths
Sealifting
Mackenzie River / Barge
Ice Roads
Gravel Roads
Railway
Major Roads
Trans Canada Highway

3.0 Energy Retrofit Considerations for the North

Home energy retrofit projects generally consist of improving home airtightness, increasing insulation levels, and replacing mechanical systems and other building elements with more energy-efficient products. These activities are usually consistent across different climates; however, there are several retrofit considerations that are unique to the North. The severe arctic climate and remoteness of many communities is responsible for a distinct building typology and heavily influences available equipment and material choices.

Permafrost and Foundations

Many buildings in the North are constructed over permafrost, particularly at higher latitudes, where upward and downward movement in the ground surface (frost-heave and thaw settlement, respectively) occurs as temperatures fluctuate around freezing. Many northern homes are constructed on elevated foundations such as screw jacks and pads, cribbing, steel piles, wood piles, or space frames in order to accommodate ground movement and to prevent building heat from melting the permafrost below. Elevated foundations also allow drifting snow to pass freely beneath the building, improving safety and reducing the annual expense of snow removal. As a result, most homes are constructed with exposed floors that must be more highly insulated and airtight than a conventional foundation system. Furthermore, many HVAC system inlets and outlets may be directed through the floor instead of the walls due to drifting snow, leading to unique air sealing considerations that need to be addressed during an energy retrofit.

It is important to confirm the condition of existing foundations prior to beginning an energy retrofit project: the foundations must perform adequately and remain serviceable after the energy retrofit work is completed. Furthermore, a program of energy retrofits may present an opportunity to renew or replace deteriorating foundations such as wood piles or cribbing. In some cases, existing foundation failures may provide the impetus for a full building upgrade.

HVAC Equipment Efficiency

Mechanical system upgrades can be challenging in the North. When more energy-efficient combustion appliances are utilized, the flue exhaust gas temperature is decreased as more fuel energy is converted to useful heat indoors. These exhaust flue gases are at a higher risk of freezing and could potentially plug or break the exhaust vent. This can result in harmful combustion gases, such as carbon monoxide, spilling into the home. As a result, combustion appliance energy efficiency may be limited when energy retrofits are undertaken unless the flue is redesigned and properly sized and insulated.

Material Availability and Durability

In the North, many construction materials are not readily available and are excessively expensive, particularly in remote communities where materials must be shipped in by barge or flown in by plane. This places limitations that would otherwise not exist on many energy retrofits. Material availability should always be confirmed prior to completing energy retrofits in order to ensure that the specified building materials can be obtained.

Many materials available in the South, may not be suitable for northern climates. For example, vinyl siding and some tapes and membranes may be become brittle and fail when exposed to extreme cold. Care must be taken to ensure all construction materials will function as intended when utilized in the North.

Upper | Single detached home in Yellowknife, NWT constructed over permafrost.

Lower | Frozen flue gases at the top of a combustion appliance vent.

4.0 Health and Safety Considerations

With proper precautions and training, energy retrofit work on homes should pose little to no threat to the health and safety of the contractor or the occupants of the home. However, improperly used building materials and tools can be dangerous to users or occupants, or can damage the building, so it is important that contractors read and follow all manufacturers' recommended safety and installation procedures. Wherever possible, less harmful and lower VOC air sealing and insulation materials should be used, particularly if materials will be exposed to interior living space.

The following pages summarize some of the key points to consider, with references provided for further information and local occupational health safety procedures. It should be noted that the health and safety information in this guide is neither comprehensive nor complete, and those performing weatherization work should always be appropriately trained and aware of the safety risks associated with the work.

Structural Elements and Connections

Structural elements of the home should not be compromised during weatherization work even if it is necessary to cut, drill, or relocate wood structural elements during renovation work. Contractors should avoid cutting wood elements such as studs, trusses, joists, and beams when air sealing or insulating unless a structural engineer has been retained to review the modifications and suggest remedial or reinforcing techniques. Any structural elements that have been compromised due to previous moisture issues must be prepared at the time of the energy retrofit project.

Ventilation of the Home

Air sealing work may seal openings in the building enclosure that were previously relied on for natural or passive ventilation in the home. Essentially, as the building becomes more airtight, more mechanical ventilation is necessary. Inadequate ventilation can lead to indoor air quality concerns and moisture problems; therefore, a properly functioning and appropriately sized mechanical ventilation system is critical. HRVs are the most efficient mechanical appliance for supplying additional ventilation in airtight homes. Further information can be found in numerous resources on ventilation system design including Chapter 18 of the "*Canadian Home Builder's Association Builders' Manual*" and the "*HRAI Residential Mechanical Systems Manual*".

Ventilation while Performing Work

Many sealants, adhesives, and spray polyurethane foams release VOCs and other potentially harmful chemicals when curing. The product manufacturers' installation and safety procedures should be followed when performing work, and ventilation should be provided as required: opening windows, using temporary ventilation fans, or using full respiratory equipment, depending on the nature of the work being performed. In some cases—for example, when using large quantities of spray polyurethane foam in attics, roofs, or walls—contractors need full respiratory equipment while in the work area and homeowners may need to leave the house for up to 24 hours after spraying, where all windows are kept open for a full-house flush. Note that there is an increasing number of available products that release little or no VOCs.

Asbestos-containing Products and Vermiculite Insulation

In many older homes, asbestos fibres may be found in building products such as vermiculite insulation, drywall joint compound, stucco, flooring and flooring adhesives, and some older window putties. Several older mechanical and electrical items also contain asbestos including pipe insulation, chimneys, furnaces, boilers, and hot water heaters (liners and gaskets). Undisturbed materials within walls or attic spaces pose little risk to occupant health. However, if exposed or disturbed as part of a weatherization program, these materials can cause health risks to both the contractor and homeowner. At a minimum, contractors and homeowners should consult some of the publications listed below prior to undertaking weatherization work as appropriate safety measures must be followed:

- "*General Guidelines – Asbestos Removal and Disposal*", published by the Government of the Northwest Territories
- "*Asbestos Abatement*", published by Workers' Safety & Compensation Commission
- "*Management of Waste Asbestos*", published by the Government of the Northwest Territories
- "*Environmental Guidelines for Waste Asbestos*", published by the Nunavut Department of Environment

Lead Paint

Lead can be found in many paints and coatings in older buildings. Lead-containing paints and coatings do not present a danger if they are left intact; however, touching lead-based paint can be hazardous, particularly to small children. If retrofit work damages or removes materials containing lead, appropriate safety measures must be followed. Further information can be found in the "Guideline for Management of Waste Lead and Paint", published by the Government of the Northwest Territories and available online (www.enr.gov.nt.ca).

Sprayfoam Insulation

Spray polyurethane foam (SPF) is a commonly used air sealing and insulation material for weatherization work and this guide suggests its use in various applications. Exposure to isocyanates and other chemicals in the sprayfoam during the curing period or for some time after installation may cause health effects in some people. Care must be taken to control exposure to contractors and the homeowner, including possibly vacating the home while sprayfoam is being applied and for up to 24 hours after for large applications. In addition, some sprayfoam types (closed cell, medium density products) can only be applied in lifts of up to 2" at a time, should not be used to fill closed cavities such as walls or floors, and require a cooling-off period between lifts for thicker applications.

Sprayfoam should always be installed by a trained contractor; this guide does not provide information or instruction on SPF installation and safety procedures. Refer to the sprayfoam manufacturer for health and safety information.

It should be noted that sprayfoam should only be applied when the substrate is above the manufacturer specified temperature. In practice, this often limits the application of sprayfoam in the North to the warmer months of the year, when temperatures are less severe.

Materials Containing Solvents, VOCs, and Toxins

Sealants, adhesives, and other products used for air sealing and insulation weatherization work may contain flammable solvents and VOCs that can affect contractor or homeowner health and safety. Low VOC options for many adhesives, paints and sealants are available and should be used when possible for indoor work, though the use of higher VOC products may be required for some applications. Additional health and safety information can be found by reviewing the product literature and manufacturers' material data safety sheets.

Some glues and preservatives found in pressure treated lumber and manufactured wood products contain formaldehyde, arsenic and other toxins. While these materials are necessary for many construction activities, care should be taken to limit exposed skin when working with certain wood products such as chromated copper arsenate (CCA) treated lumber.

Mould, Fungal Growth, and Moisture Damage

Fungal contamination and mould can occur in homes and concealed building enclosure assemblies if the materials are exposed to elevated relative humidity levels (typically above 80% RH for extended periods) and/or condensation. Organic materials, such as paper-faced drywall and wood, are susceptible to fungal growth in the home. Fungal growth is common in bathrooms, but easily removed by regular household cleaning. Fungal growth on window frames may occur if there is excessive condensation due to high indoor relative humidity levels. Fungal growth is commonly found in crawlspaces, attics, walls (particularly below windows), and other damp spaces as a result of elevated relative humidity levels, air leakage, condensation, snow and rain, and plumbing and appliance leaks. Depending on the severity and duration of the wetting, fungal growth can lead to decay and deterioration of wood components. Moisture-damaged wood is often uncovered during weatherization work.

If significant fungal contamination or mould is present or suspected in the home, it must be removed and cleaned and the contributing source addressed prior to any air sealing and insulation weatherization work. To control and reduce the potential for mould growth, indoor moisture sources and indoor humidity must be controlled. This can be achieved by the combination of a proper ventilation system with good distribution in the home, and source moisture control.

Where mould growth is severe or moisture damage is extensive, a professional specializing in mould clean-up and structural repair should be retained. The Canadian Construction Association has released comprehensive guide titled "Mould Guidelines for the Canadian Construction Industry" that provides information on mould health risks, prevention, assessment, and remediation. Alternatively, the document "Guidelines on Assessment and Remediation of Fungi in Indoor Environments", published by the New York City Department of Health and Mental Hygiene, is also a good reference for remediation procedures.

Combustion Safety

Air sealing and other energy retrofit work can affect the combustion safety of a home. Natural aspirating combustion equipment—such as pellet and wood stoves and oil-burning appliances like boilers, furnaces, or water heaters—may rely on a degree of natural air leakage through the enclosure to provide the make-up air for combustion. Some homes have dedicated combustion air vents that must be unplugged if previously plugged and that must not be sealed during weatherization work. If air sealing work is performed on a home with a natural draft chimney, the make-up air may be reduced to a point where the equipment may backdraft and spill combustion gases into the home. After air sealing work is undertaken, a direct supply of combustion air for the combustion appliance and make-up air for the exhaust appliances may be required. It should be noted that discharge air from clothes dryers and other household appliances can reduce the fresh air supply within a building. This should be accounted for when determining the amount of make-up air needed for combustion equipment.

New combustion appliances installed during energy retrofits may cause chimney damage or plugging, increasing the risk of harmful combustion gases spilling into the home. Higher-efficiency products have lower temperature flue gases that may be at greater risk of freezing in the far North, and could limit the selection of furnaces and other combustion appliances unless more extensive upgrades are performed.

Retrofit work in homes with oil- or wood-burning equipment requires special consideration and combustion safety testing. Guidance for addressing combustion safety, testing, and remedial measures are beyond the scope of this guide. Several references are provided in the *Additional Resources* section at the end of this guide. Contractors performing retrofit work should be trained on these issues prior to performing any work.

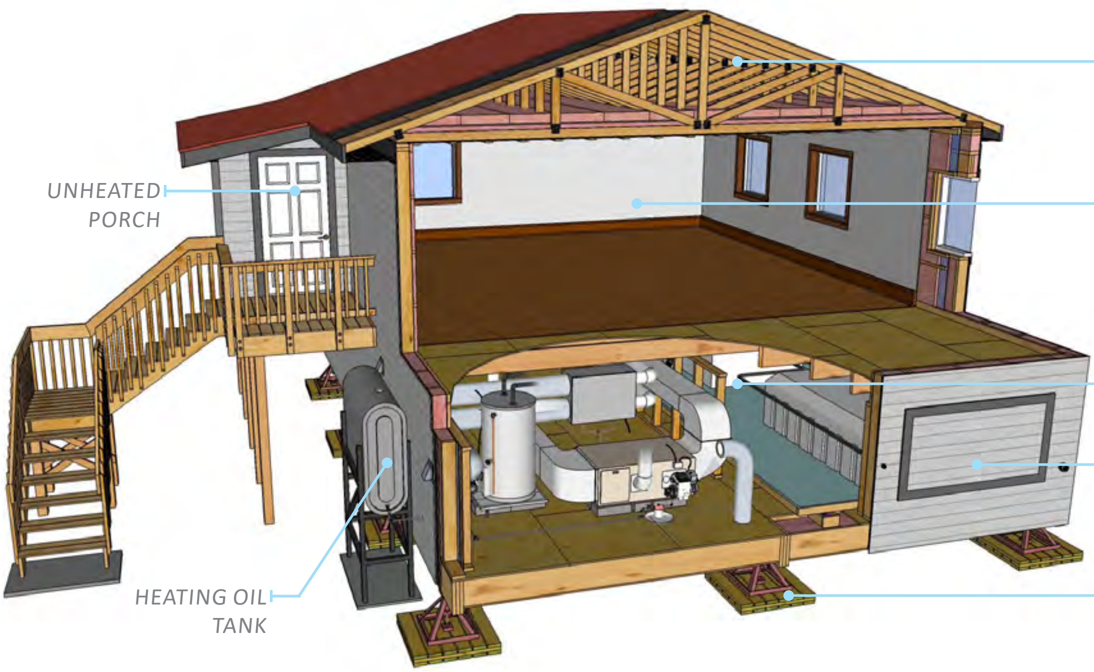
Electrical Wiring

Care must be taken when working around electrical wiring so as not to receive a shock, damage the wiring, or cause a fire. Air sealing materials such as sprayfoam should never be applied within electrical boxes or come into contact with bare wires. Always avoid burying electrical wires in sprayfoam: the heat build-up in heavily loaded wiring may cause damage to the wiring sheathing. Always follow product manufacturers' instructions and warnings, and hire an electrician if any electrical work is required, such as installing new fans or motorized dampers to provide mechanical ventilation after air sealing work is performed.

Other Considerations

Weatherization work can sometimes uncover other issues in a house. For example, exhaust fans may be directly vented into attics instead of outdoors, or a roof or window may be found to be leaking. In these cases, these problems must be addressed before or as part of the retrofit work.

5.0 Energy Retrofit Packages



Upper | The archetype home

Lower | Services in crawlspace

The archetype House

An archetype home was developed for homes on permafrost in the Northwest Territories, Nunavut, and northern Yukon. The archetype home is 1-2 storeys with a floor area of 99 m^2 (1064 ft^2). The building is balloon framed with floor joists supported on interior pony walls. Note that platform framing is also utilized in the North - different framing arrangements will impact several of the air sealing and insulation retrofits in this Guide.

The building exhibits many building characteristics that are unique to the North:

- Permafrost footings and/or foundations are included in order to mitigate seasonal ground movement; as a result, the floor is fully exposed to the exterior.
- An exterior oil tank is needed to supply mechanical equipment. Most furnaces and water heaters utilize heating oil in the North.
- An unheated vestibule (cold porch) provides additional storage space for the occupants at the main or secondary entrance (winter gear, etc.).
- A heated crawlspace will often contain the mechanical equipment along with water and sewer tanks (in remote communities without utility connections). The crawlspace is accessed through the interior of the home; however, an exterior access door is present for emergency repairs.
- The attic is unconditioned and typically accessed from an exterior hatch. However, it should be noted that in the High Arctic vented attics are not used.

Due to severe climate and high energy rates, housing affordability has long been a major challenge for homeowners in the North. Buildings must be highly insulated and airtight to mitigate extreme environmental loads as compared to other Canadian climates, and building materials and labour are often difficult and expensive to procure. Furthermore, the cost of heating fuel and electricity in the North is among the highest in Canada, and in many remote communities the local utility supply can be intermittent and overloaded. In this context, building energy efficiency retrofits become an attractive solution to increasing housing affordability and reducing pressure on local utility grids.

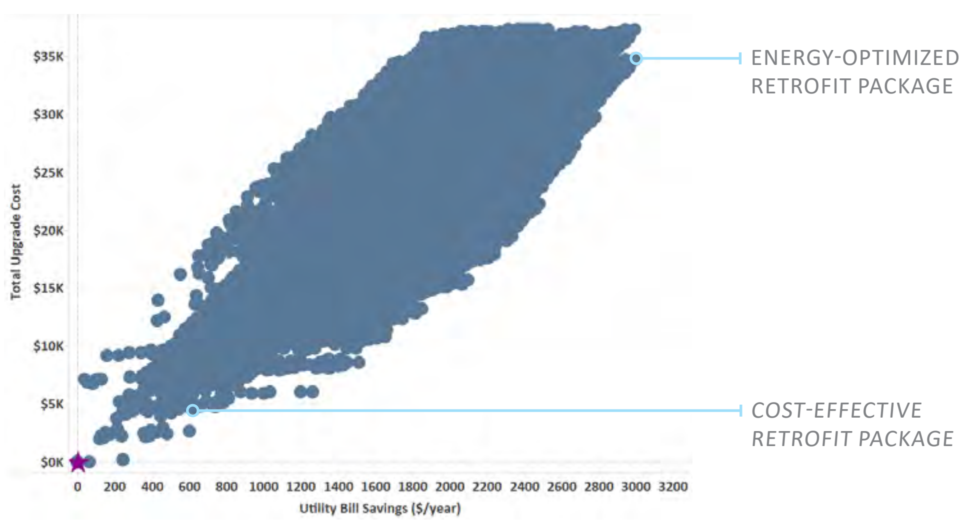
However, selecting the optimal package of energy efficiency measures can be challenging with building enclosure, HVAC, and other equipment retrofits having differing costs and energy savings. Recent work by CanmetENERGY-Ottawa and Natural Resources Canada in partnership with Canada Mortgage and Housing Corporation (CMHC), has resulted in an optimization tool that can analyze the most energy optimal and cost effective retrofit combinations for northern residential buildings. The project is targeted at homes that were constructed between 15 and 35 years ago that are presently in need of retrofits. The energy modeling is based around an archetype home that is 99m^2 (1064ft^2) located in N'Dilo, Northwest Territories that was constructed in the 1990s and currently has a \$6300/yr utility bill.

Over 48,000 retrofit packages were modelled including upgrades to different mechanical equipment, improved airtightness, and adding insulation to different enclosure assemblies in order to determine the optimal retrofit strategy. A variety of inputs were selected for the modeling, including; material availability, construction design, material and labour costs, energy efficiency and local utility rates.

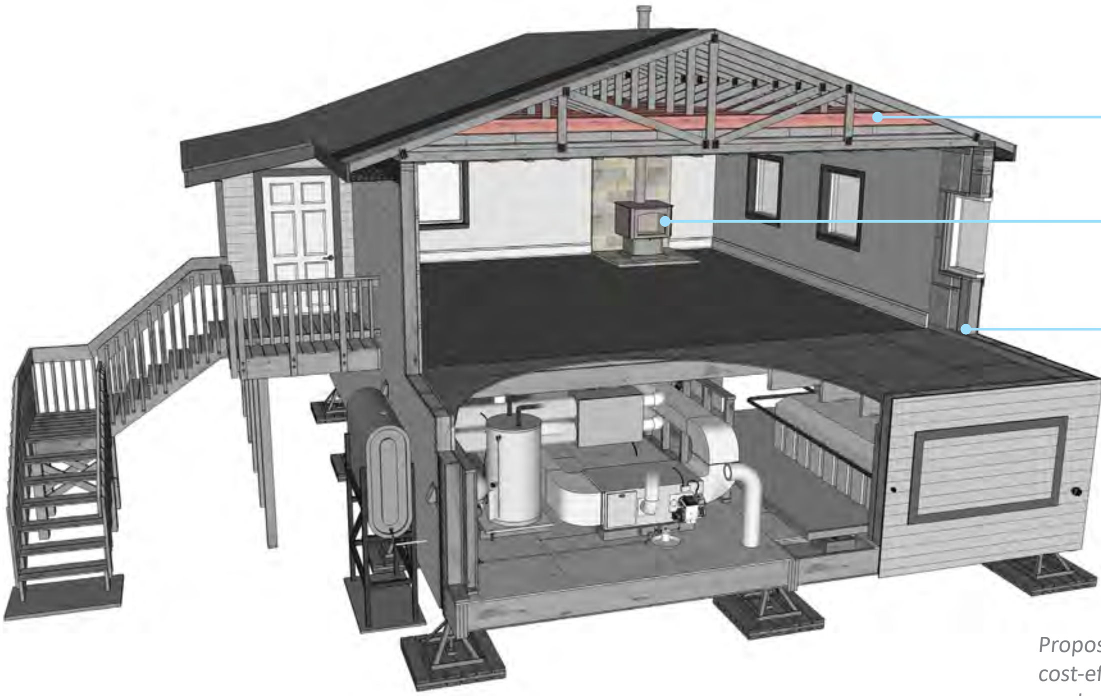
Important output metrics of the optimization scenarios are the cost effective retrofit package and the energy optimized retrofit package for the archetype home. The figure below identifies the location of the various upgrade options relative to the base case scenario at the XY axis intercept where each blue point represents each of the potential >48,000 retrofit packages.

For the purpose of this guide, the cost-effective retrofit package costs approximately \$5000 and has utility savings in the range of \$500-\$1000 per year. The energy-optimized retrofit package costs approximately \$33,000 and has utility savings approaching \$3000 per year. The various unique components that make up both of these retrofit packages are covered in the following sections of this guide.

The following tables and graphics present the combination of components and assemblies for the cost-effective retrofit package and the energy optimized retrofit package as compared to the base case home. The individual energy efficiency retrofits are further detailed later in this guide.



5.1 COST-EFFECTIVE BUILDING RETROFIT PACKAGE



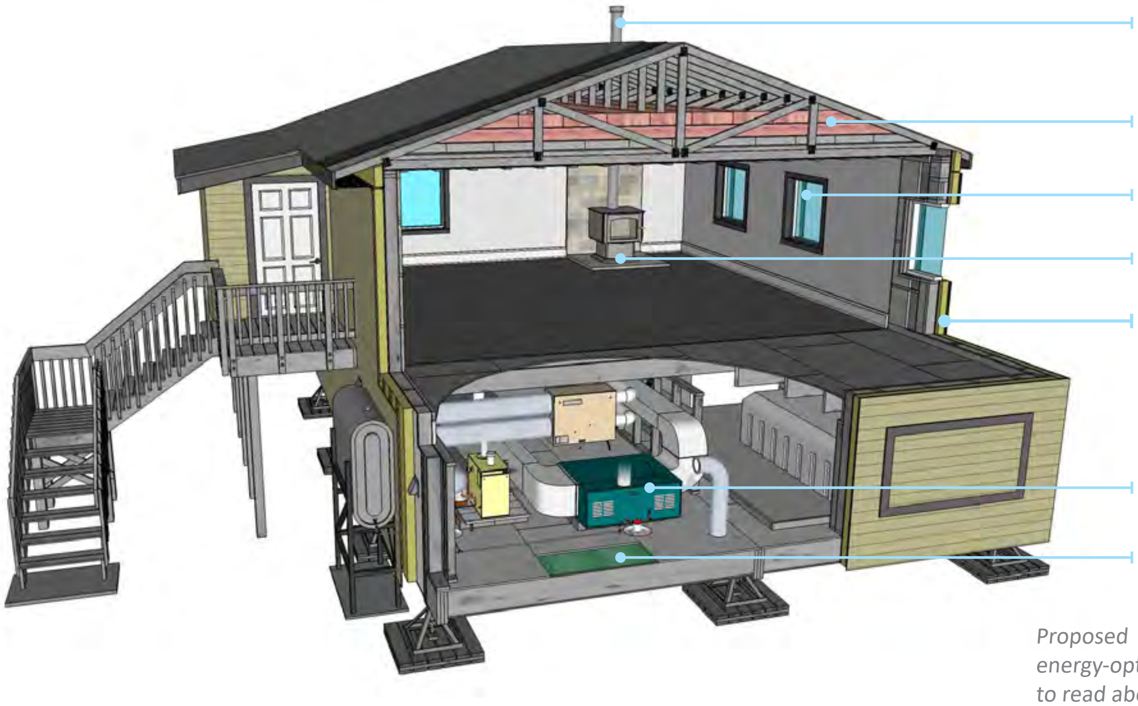
Proposed retrofits and upgrades for cost-effective retrofits and where to read about them in this guide.

BASE CASE BUILDING vs COST-EFFECTIVE BUILDING RETROFIT PACKAGE

Category	Base Case	Cost Effective
Airtightness	3.5 ACH (air changes per hour)	2.5 ACH (air changes per hour)
Attic	Standard truss @ 610mm (24") o.c. with batt insulation, RSI 7.0 (R-40)	Standard truss @ 610mm (24") o.c. with additional batt insulation, RSI 10.6 (R-60)
Exposed Floor	2X12 Joists @ 610mm (24") o.c. with batt insulation in floor joist cavities, RSI 4.0 (R-23)	2X12 Joists @ 610mm (24") o.c. with batt insulation in floor joist cavities, RSI 4.0 (R-23)
Walls	2X6 Wood stud @ 610mm (24") o.c. with batt insulation and 38mm (1.5") semi-rigid insulation interior, RSI 4.0 (R-22.8)	2X6 Wood stud @ 610mm (24") o.c. with batt insulation and 38mm (1.5") semi-rigid insulation interior, RSI 4.0 (R-22.8)
Windows	Double-glazed, low-e, argon	Double-glazed, low-e, argon
Furnace	Oil, 60% AFUE (ducted forced air)	Oil, 60% AFUE (ducted forced air)
Domestic Hot Water	Oil, 0.55 EF	Oil, 0.55 EF
Heat Recovery Ventilation	Yes (70% SRE @ 0°C)	Yes (70% SRE @ 0°C)
Pellet Stove[1]	No	Yes (79.9% AFUE)
Upgrade Cost	$0	$5000
Yearly Utility Cost Savings	$0	$621 (Simple Payback = 8 years)

[1] *Pellet stove not included in energy modeling*

5.2 ENERGY-OPTIMIZED BUILDING RETROFIT PACKAGE



Proposed retrofits and upgrades for energy-optimized retrofits and where to read about them in this guide.

BASE CASE BUILDING vs ENERGY-OPTIMIZED BUILDING RETROFIT PACKAGE

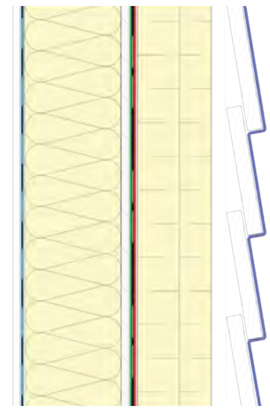
Category	Base Case	Energy Optimized
Airtightness	3.5 ACH (air changes per hour)	2.0 ACH (air changes per hour)
Attic	Standard truss @ 610mm (24”) o.c. with batt insulation, RSI 7.0 (R-40)	Standard truss @ 610mm (24”) o.c. with additional batt insulation, RSI 14.1 (R-80)
Exposed Floor	2X12 Joists @ 610mm (24”) o.c. with batt insulation in floor joist cavities, RSI 4.0 (R-23)	2X12 Joists @ 610mm (24”) o.c. with batt insulation in floor joist cavities, new blown-in cellulose insulation, RSI 7.0 (R-40)
Walls	2X6 Wood studs @ 610mm (24”) o.c. with batt insulation and 38mm (1.5”) semi-rigid insulation interior, RSI 4.0 (R-22.8)	2X6 Wood studs @ 610mm (24”) o.c. with batt insulation and 38mm (1.5”) semi-rigid insulation interior, new 100 mm (4”) exterior insulation, RSI 8.3 (R-47)
Windows	Double-glazed, low-e, argon	Triple-glazed, low-e, argon
Furnace	Oil, 60% AFUE (ducted forced air)	Oil, 83% AFUE (ducted forced air)
Domestic Hot Water	Oil, 0.55 EF	Tankless, Oil, 0.83 EF
Heat Recovery Ventilation	Yes (70% SRE @ 0°C)	Yes (78% SRE @ 0°C)
Pellet Stove[1]	No	Yes (79.9% AFUE)
Upgrade Cost	$0	$33,000
Yearly Utility Cost Savings	$0	$2,821 (Simple Payback = 12 years)

[1] *Pellet stove not included in energy modeling.*

6.0 Building Science Primer

The building enclosure is a system of assemblies, comprised of various materials and components, which work together to physically separate the exterior and interior environments. The materials and components within the assemblies form critical barriers that function to control: water, air, heat, water vapour, sound, light, and fire.

A critical barrier is a layer within the assembly that is essentially continuous in order to perform its control function. The critical barriers discussed in this guide are the water shedding surface (WSS), the water-resistive barrier (WRB), the air barrier (AB), vapour retarder (VR), and thermal control. In some cases a material or component will perform multiple functions. As an example, in an above grade wall assembly with an exterior air barrier approach, the sheathing membrane will form the water resistive barrier and the air barrier as will be explained in more detail below.



Locations of Critical Barriers Shown in a Split Insulation Wall Assembly

WSS - The water shedding surface is the primary plane of protection against bulk water loads and is also known as the first plane of protection within the building code. It is commonly the most exterior materials or components of the enclosure (cladding, flashing, etc.).

WRB - The water-resistive barrier is the secondary plane of protection against bulk water movement and also known as the second plane of protection within the building code. It can also be considered the innermost plane that can safely accommodate water, and allow drainage without incurring damage. In residential construction the WRB is usually performed primarily by the sheathing membrane, tapes and sealants behind exposed cladding.

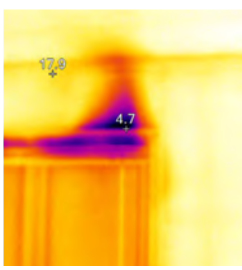
AB - The air barrier resists the movement of air between the indoor and outdoor environments. The interface detailing between components is essential to the function of the air barrier and the control of air movement. If the barrier is discontinuous, uncontrolled air will be allowed to pass through the assembly resulting in reduced energy efficiency and the potential accumulation of water in the wall assembly due to condensation. In this guide, the AB is primarily the taped and sealed sheathing membrane. Careful attention is paid to interfaces between the sheathing membrane and other materials and components to ensure air barrier continuity. Within the wall example above, the sheathing membrane is the primary air barrier; however, the interior polyethylene vapour barrier is also often made airtight for supplemental airflow control.

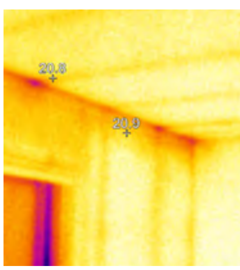
VR - The vapour retarder is designed to resist the movement of water vapour through the assembly. In cold climates, the VR must be on the warm side of the insulation to ensure that the bulk of water vapour is slowed down before it comes into contact with cold surfaces where it could condense. Most commonly, a 6 mil polyethylene sheet is used as the VR. In many cases, it also forms the air barrier; however, as shown in this guide other materials, such as she sheathing membrane, may form the primary air barrier.

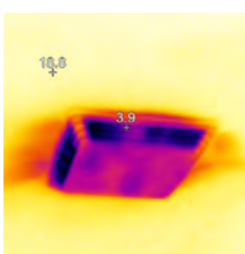
Thermal control - Thermal control is usually made up of one or more layers that are as continuous as possible to resist the flow of heat through the building enclosure. Thermal bridging occurs when a material or component allows a disproportionate amount of heat flow through the building enclosure as opposed to the surrounding insulation. An example of a thermal bridge in a wall assembly are the wood studs. An effective way of minimizing this thermal bridging is to add continuous exterior insulation outside the sheathing thereby breaking the direct heat flow through the studs.

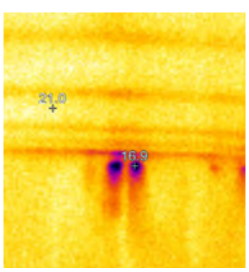
Note that the ratio of exterior to stud cavity insulation is an important consideration when designing the thermal control system. If the majority of insulation is installed outboard of the sheathing, a relatively vapour impermeable insulation (XPS, EPS, etc.) may be utilized safely. However, when a significant amount of the wall thermal resistance comes from stud cavity insulation (greater than one-third of total R-Value): a vapour permeable insulation should be used.

7.0 Identifying Air Sealing Locations









Upper | Typical blower door system installed in door frame for whole building airtightness testing.

Centre Left | Window frame

Centre Right | Ceiling to wall interface

Lower Left | Bathroom fan

Lower Right | Plumbing stack through top plate

It is important to identify the size, location, and distribution of air leaks in a building before extensive air sealing measures are taken. No two buildings are exactly the same and air leakage locations may differ substantially across similar buildings. For this reason, a home-specific air leakage evaluation should always be completed prior to energy retrofit work in order to focus air sealing efforts and get the best savings for the investment.

There are a number of visual techniques and test procedures that can be utilized to find leaks and quantify the air leakage characteristics of a building:

1. Whole Building Airtightness Testing

   A certified energy advisor (CEA) or other airtightness certified professional can conduct whole-building air leakage testing by pressurizing and/or depressurizing the building using a large calibrated fan. A blower door system, as the fan system is often called, is temporarily installed into an exterior door and the rate of air leakage through the building is then measured. The resulting air leakage value, measured in air changes per hour (ACH) and equivalent leakage area (ELA), can be utilized to determine air sealing opportunities. Generally, a large ACH or ELA indicates that there are significant air sealing opportunities that can be addressed. It should be noted that while air leakage testing can provide quantitative information on the leakiness of a building, further test methods and observations are needed to establish the exact location of air leaks. A follow up airtightness test can be completed post retrofit to gauge the effectiveness of completed air sealing measures.

2. Infrared Thermography

   An infrared camera can be utilized to pin-point air leakage and thermal bridging locations by providing a thermal image that contrasts temperature differences across the building enclosure. Areas that are warmer are usually represented by brighter (more red) colours, while areas that are cooler are represented by darker (more blue) colours. Air leakage/thermal bridging locations will appear darker than surrounding elements if the image is taken from inside the building enclosure. The infrared images at left identify several common areas that should be addressed with improved air sealing in order to reduce heat loss. Infrared thermography is most effective when completed during building airtightness testing.

Upper | Tracer smoke testing for air leakage at roof wall interface above window

Lower | Possible air leakage location at gap in drywall

1. Smoke Pencils or Puffers

   Tracer smoke can be used to visually observe air leakage at problematic locations. When there are discontinuities in the air barrier, smoke will follow air movement through cracks and gaps in the building enclosure. Smoke testing is best completed at the same time as a whole-building airtightness test. Air leaks can then be more easily observed on the exterior of the building.

4. Visual Inspection

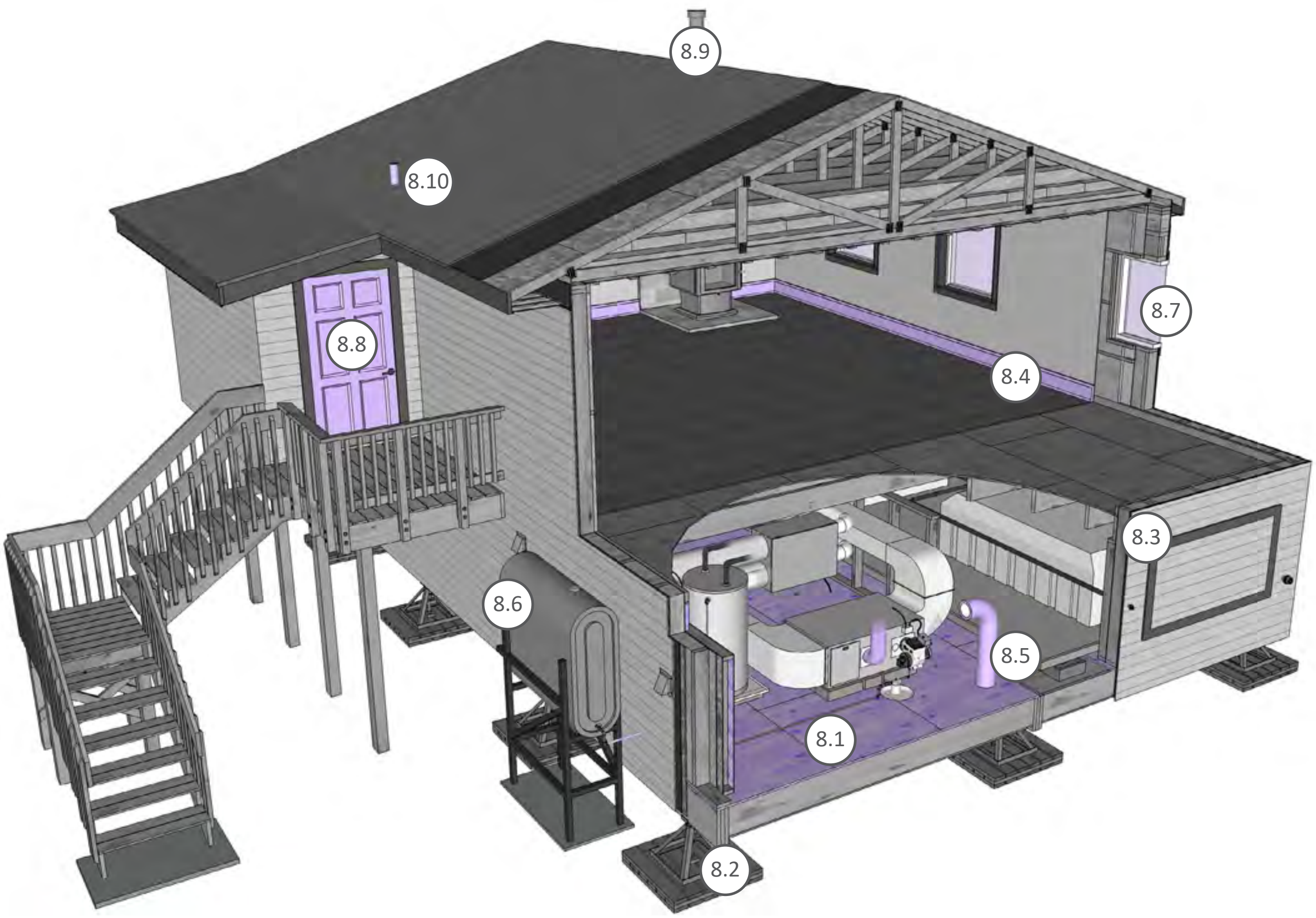
   Many air leakage locations can be discovered by completing a thorough visual inspection of the building interior, particularly at interfaces and penetrations. Common problem areas usually include window and door weatherstripping and gaskets. Generally, air leakage locations appear as gaps or cracks in building walls, floor, or ceiling. Drafts or cold spots in the building enclosure may also indicate problem areas.

While some air leaks can be identified by the homeowner or tenant simply by visually searching for building inadequacies, under most circumstances it is recommended that a professional be hired to complete comprehensive air leakage testing. The following section will address several common air leakage locations as well as techniques that may be utilized to reduce air leakage at problematic locations. It should be noted that the most cost-effective air sealing measures are easily accessible and do not involve removing other building components. In practice, this often means air sealing interior details such as gaps in the gypsum wall board as opposed to air sealing the polyethylene or housewrap air barrier which is often concealed far behind interior or exterior finishes.

8.0 Potential Air Sealing Retrofits

Common air leakage locations

The following locations are common areas where air sealing measures can be completed to improve building airtightness. Note that air leakage locations should always be identified before pursuing air sealing retrofits.



8.1 - UNFINISHED CRAWLSPACE FLOOR

8.2 - BASE OF UNFINISHED WALL

8.3 - EXPOSED RIM JOIST

8.4 - BASE OF FINISHED WALL

8.5 - DUCT PENETRATION THROUGH FLOOR

8.6 - FUEL LINE PENETRATION

8.7 - WINDOWS

8.8 - EXTERIOR DOORS

8.9 - COMBUSTION APPLIANCE DUCT THROUGH CEILING

8.10 - PLUMBING VENT STACK THROUGH CEILING

*Ideally fuel tank located far away from fresh air intake

8.1 Unfinished Crawlspace Floor

Many Northern homes in permafrost regions are elevated above the ground. As a result the exposed floor and its penetrations are a large source of heat loss and potential for air leakage.

The exposed underside of the floor can be a significant source of heat loss due to air leakage and conduction. In most cases the subfloor acts as the main air barrier and vapour retarder, separating the conditioned crawlspace from the exterior environment beneath. Air sealing is required at all joints and penetrations in the subflooring sheathing.

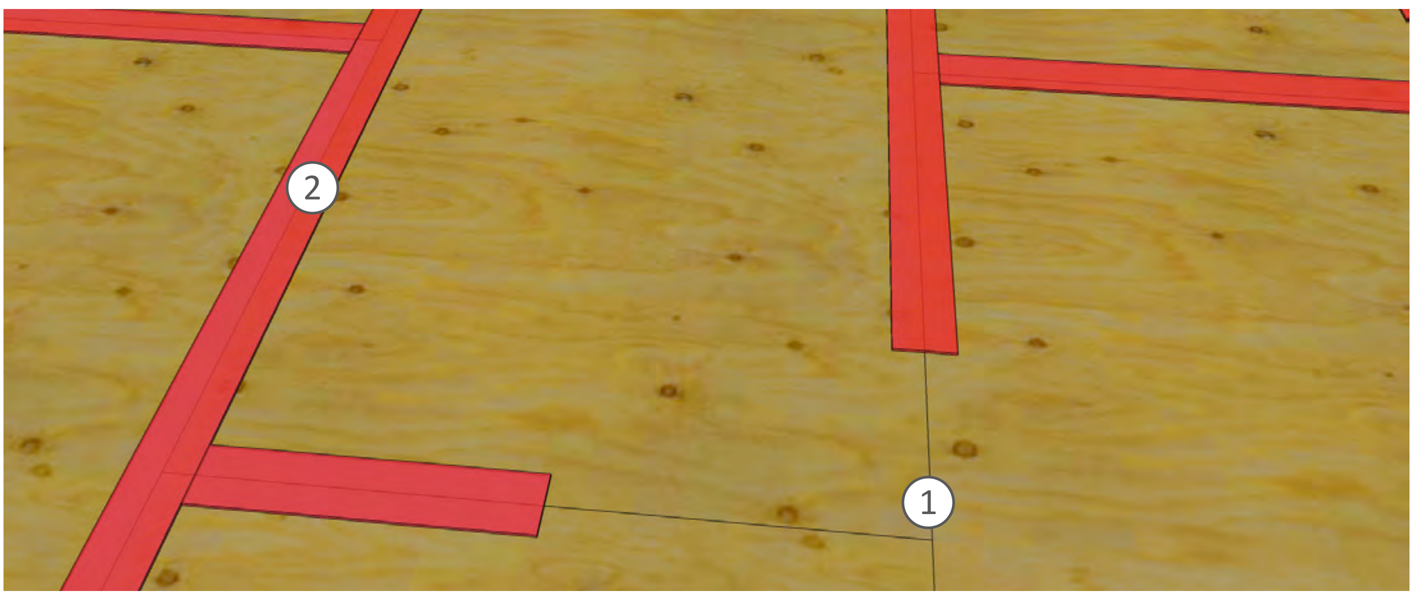
Taped plywood subflooring in crawlspace.

MATERIALS NEEDED

- Compatible tape
- Polyurethane sealant

RECOMMENDED TOOLS

- Utility knife
- Caulking gun



PROCEDURE

1. Clean plywood subflooring and remove any dirt or debris that has accumulated in the joints.
2. Tape all joints in the plywood subflooring with compatible tape.
   Ensure that the selected tape is durable and bonds well to the substrate.

COMPLETE

Note: Seal around all penetrations in the floor including passive ventilation ducts, plumbing exhaust ducts, and drains. Where the floor interfaces with framing or other obstructions, apply sealant around the perimeter of the obstacle to maintain air barrier continuity (See 8.5 for example).

8.2 Base of Unfinished Wall

In a heated crawlspace, the walls and subfloor should be sufficiently insulated and airtight to make the area space conditioned like the rest of the home. A common location of air leakage is located at the bottom of the crawlspace wall, particularly where the wall interfaces with the subfloor. Many buildings rely on a polyethylene sheet sealed to the bottom plate to transition the air barrier between the floor and wall. However, accessing the polyethylene sheet is often difficult, particularly if it lies behind structural framing. In this situation, an interior air sealing approach can be taken. This entails making a building element (OSB) inboard of the polyethylene the new air barrier.

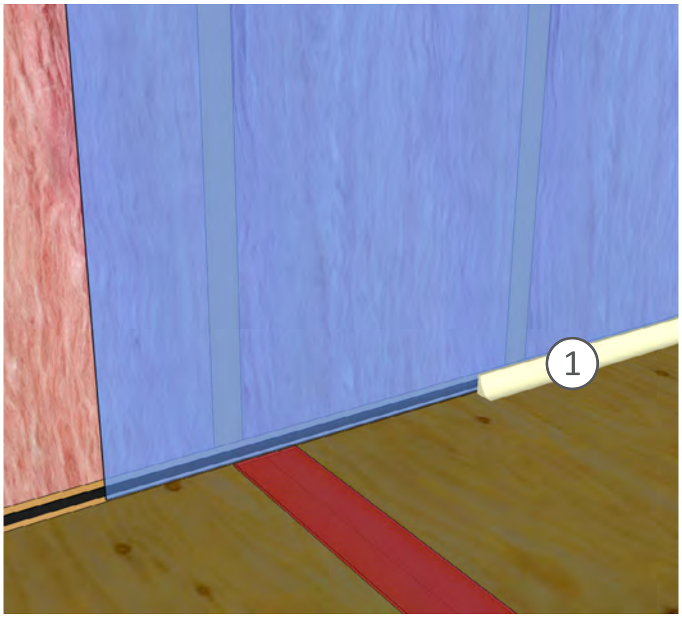
Interface between walls and subfloor (sheathed with OSB)

MATERIALS NEEDED

- Compatible tape
- Polyurethane sealant

RECOMMENDED TOOLS

- Utility knife
- Caulking gun

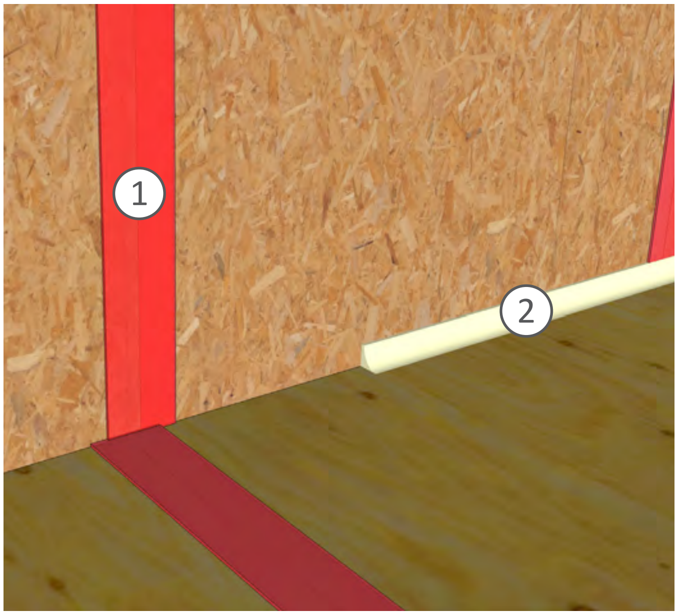


Exposed Polyethylene

PROCEDURE

1. Seal the base of the polyethylene sheet to the plywood subflooring with sealant

   COMPLETE



OSB Sheathing

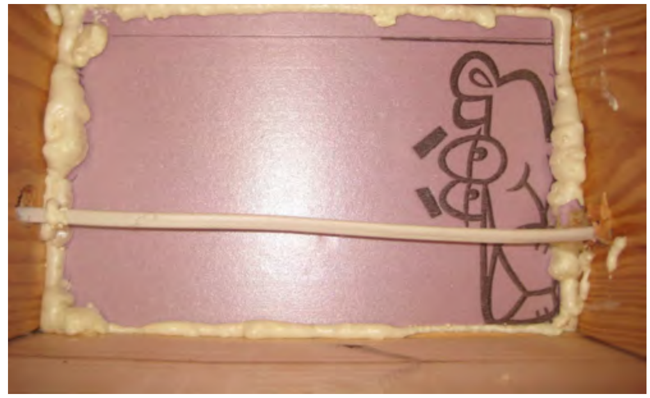
PROCEDURE

1. Tape all joints in the OSB panels with tape.
2. Seal the base of the OSB panels to the plywood subflooring with sealant

   COMPLETE

8.3 Exposed Rim Joist

At the rim joist area, many building components come together including subflooring, crawlspace sheathing, floor joists, and rim joists. There are several areas where air leakage can occur when these building components interface. To seal these air leaks and maintain continuity of the interior air barrier, air impermeable insulation such as rigid foam and sprayfoam should be used in conjunction to insulate and seal rim joist cavities.



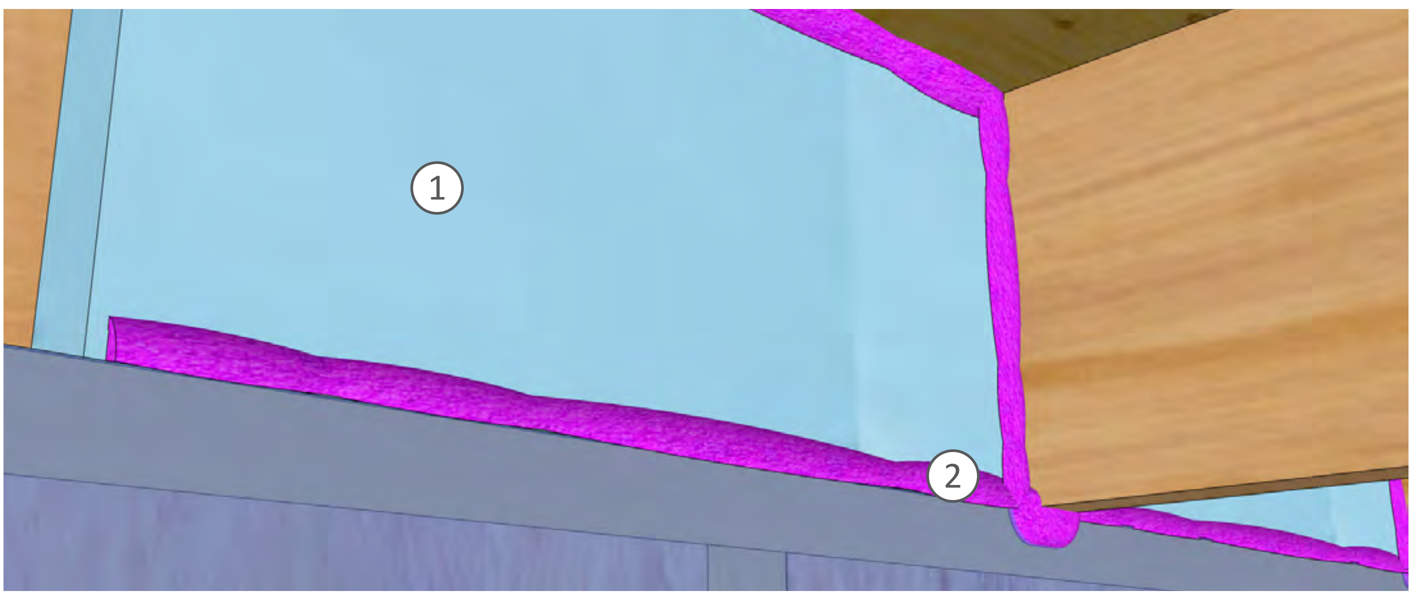
Air sealed rim joist area.

MATERIALS NEEDED

- Spray polyurethane or compatible sealant
- Rigid XPS foam board

RECOMMENDED TOOLS

- Utility knife



PROCEDURE

1. Measure and cut rigid insulation to fit snugly into each joist space and around penetrations. Install into each joist space and use multiple layers to achieve desired thickness.
2. Install sprayfoam around the perimeter of the rigid insulation, sealing it to the subfloor above, the floor joists, and the crawlspace sheathing.

   COMPLETE

   Note: Seal around all penetrations in the rim joist including fuel lines and ducting with sprayfoam or sealant.

8.4 Base of Finished Wall

A common air leakage location is often found below the drywall and baseboard trim of finished walls. While the drywall trim is not the primary air barrier of the wall, sealing any gaps at this interface can improve comfort and make small improvements to overall airtightness.

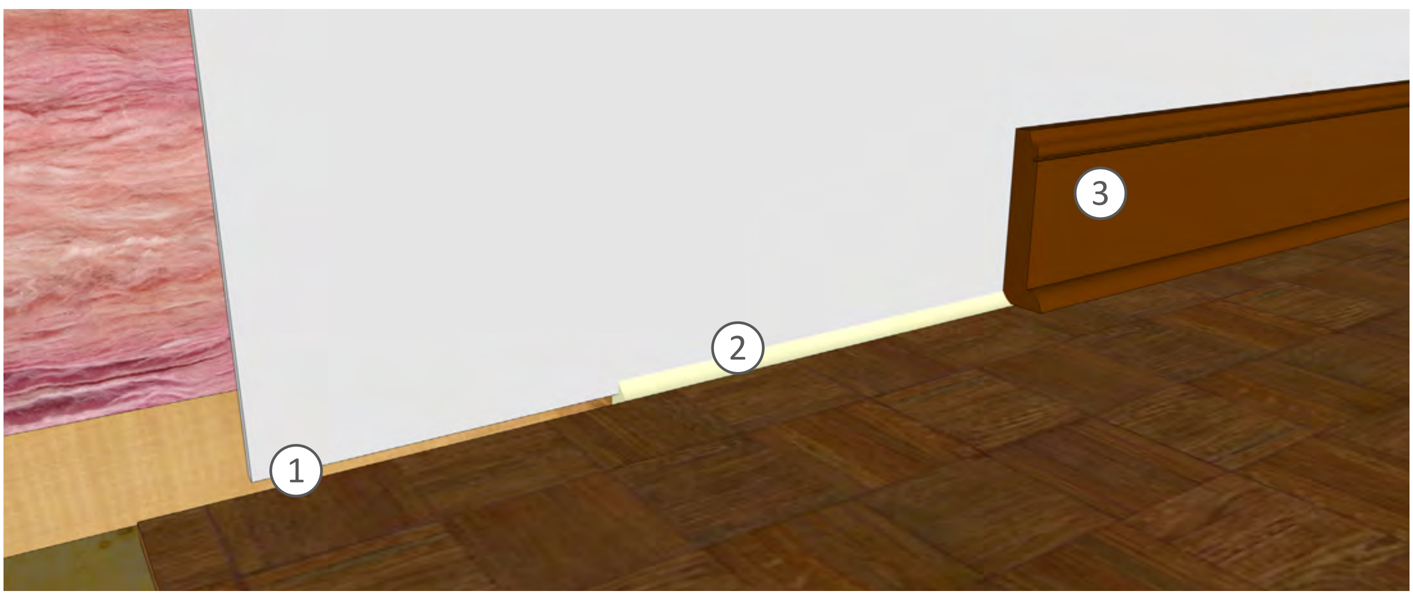
Gaps beneath drywall baseboard.

MATERIALS NEEDED

- Polyurethane sealant

RECOMMENDED TOOLS

- Utility knife
- Hammer and nails



PROCEDURE

1. Remove the baseboard and put aside for later reinstallation.
2. Install sealant between the drywall and floor sheathing, taking care to fill the space between the subfloor and the gypsum board. If large gaps exist, consider using sprayfoam sealant.
3. Reattach the existing baseboard back to the wall to hide air sealing retrofit.

COMPLETE

8.5 Duct Penetration Through Floor

Ducts (passive air inlets, bathroom fans, etc.), drain pipes, and other floor penetrations can be sealed with relative ease. Besides making floor penetration airtight, care should be taken to ensure that ducts do not leak at joints and are properly air sealed. All ducts and drains should be insulated where possible to reduce heat loss from the crawlspace.

The following air sealing procedure is relevant for all ducts and pipes that penetrate the crawlspace subfloor.

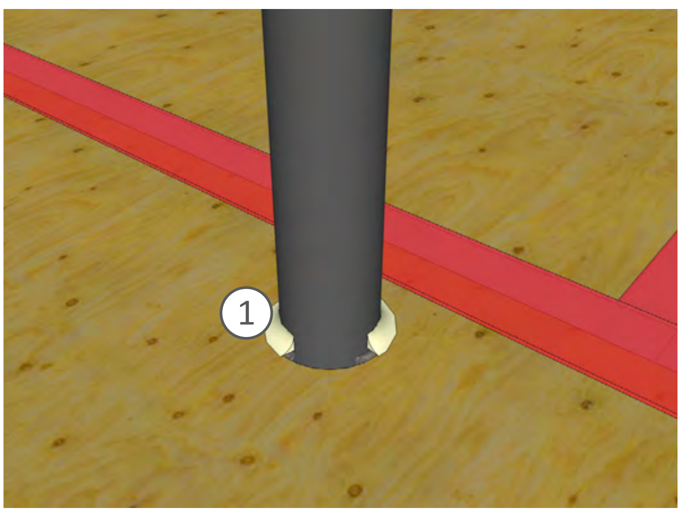
Passive air inlet penetrating through floor.

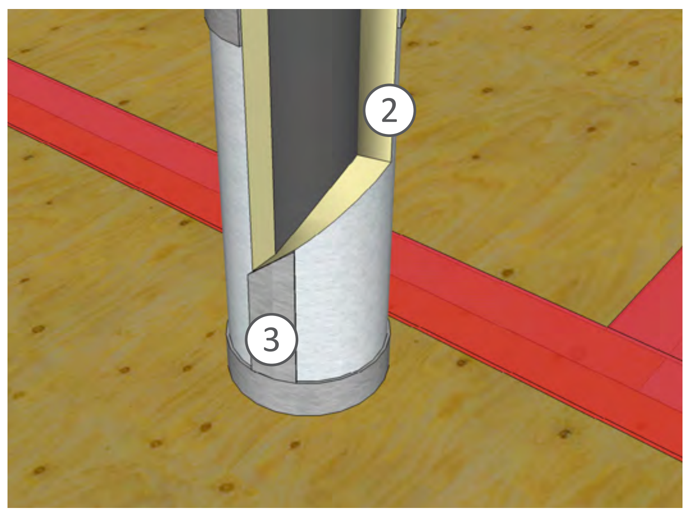
MATERIALS NEEDED

- Spray polyurethane sealant or polyurethane sealant
- Closed cell backer rod
- Insulated pipe/duct sleeve (2” glass fibre insulation) with foil or plastic cover
- Foil tape

RECOMMENDED TOOLS

- Utility knife
- Caulking gun





PROCEDURE

1. Install backer rod and sealant or sprayfoam around the perimeter of the penetration at the plywood subfloor.
2. Install insulation sleeve along the whole length of the duct or vent if not already insulated.
3. Tape all joints in the insulation sleeve with foil tape to ensure the duct vapour barrier is sealed.

COMPLETE

8.6 Fuel Line Penetration

Fuel lines, water and sewage hookups, ventilation ducts, and electrical penetrations are relatively easy to seal from the interior when accessible.

The following air sealing procedure is relevant for a fuel line penetration through the building wall.

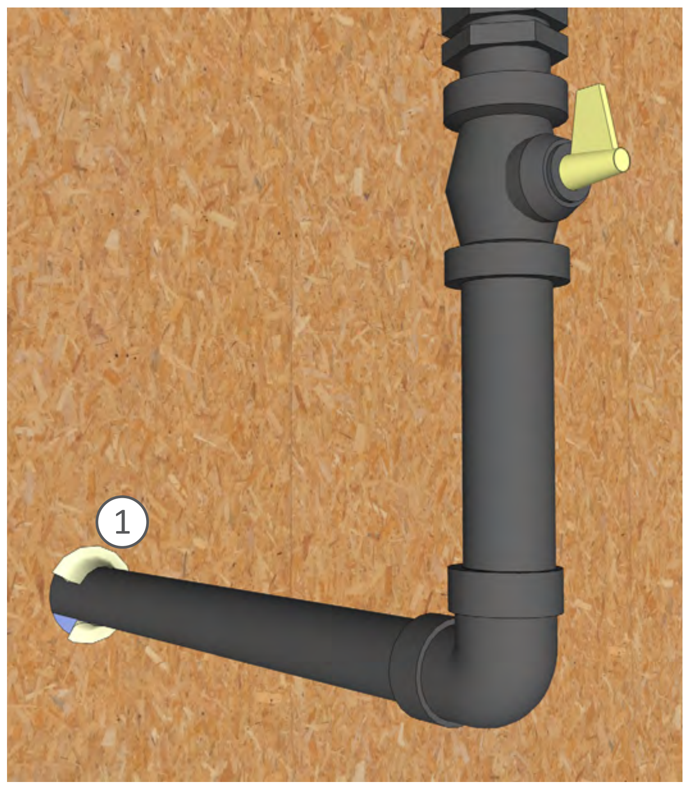
Fuel line wall penetration.

MATERIALS NEEDED

- Polyurethane sealant
- Closed cell backer rod

RECOMMENDED TOOLS

- Utility knife
- Caulking gun



PROCEDURE

1. Install backer rod and sealant around the perimeter of the penetration at the OSB sheathing.

   COMPLETE

   Note: Ensure proper safety precautions are followed when dealing with fuel lines and electrical penetrations. A qualified professional should always be present when dealing with electrical wiring or combustible fuels.

8.7 Windows

Window gaskets, weatherstripping, and interfaces are common sources of air leakage. Window air leakage is highly visible when exterior temperatures are below freezing: ice will often form above the window if the frame is not properly sealed to the rough opening.

Air leakage between the rough opening and the window frame can often be reduced by simply removing the interior trim and sealing in the gap between. Leaky operable windows are often the result of broken hardware, or deteriorated weatherstripping (gaskets). Installing new weatherstripping is also an effective air sealing strategy.

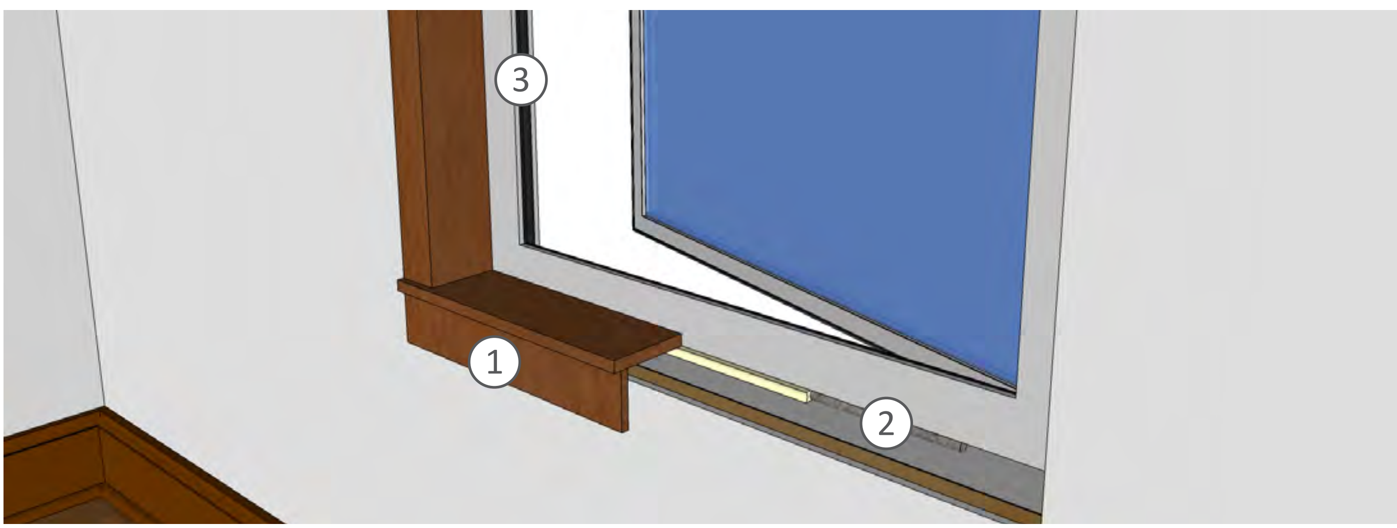
Frost around window due to poorly sealed weather stripping.

MATERIALS NEEDED

- Polyurethane sealant
  (or low-expansion sprayfoam)
- Closed cell backer rod
- Window gaskets and weatherstripping

RECOMMENDED TOOLS

- Utility knife
- Caulking gun
- Hammer and nails



PROCEDURE

1. Remove interior window trim and put aside for later reinstallation.
2. Install backer rod and sealant around the window perimeter to air seal the window.
   Low-expansion sprayfoam may also be used though it may not be as effective as caulking.
3. Remove existing weatherstripping and replace with new gasket behind the operable vent.

   COMPLETE

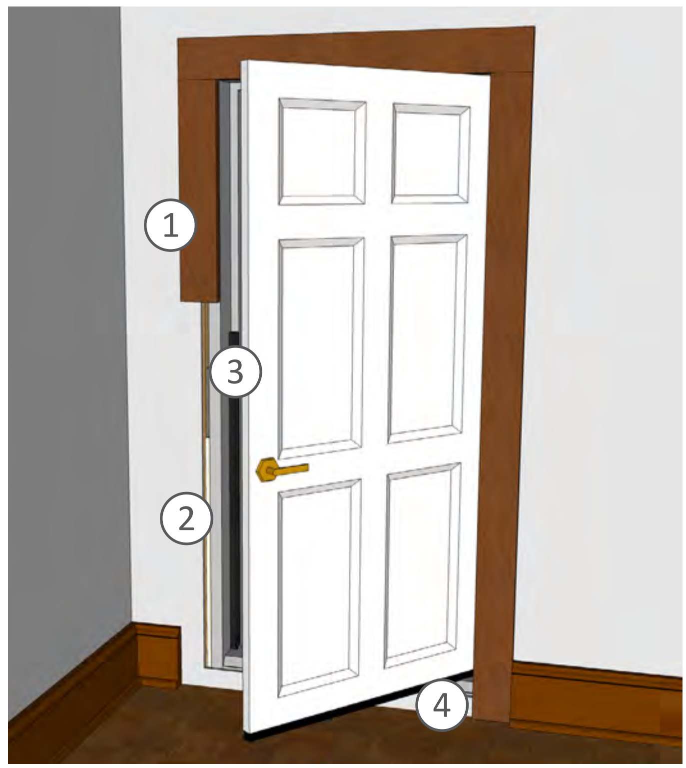
   Note: Ensure the sealant at the wall penetration is even and continuous to create an airtight seal. Consider the size of the gap to be sealed and the durability of the product when selecting appropriate weatherstripping.

8.8 Exterior Doors

Air sealing and weatherstripping entry doors is a relatively easy way to improve airtightness. Gaps between the door and door frame can be easy to find and are quickly detected. Perimeter gaskets and threshold sweeps are often deteriorated or deformed leaving pathways for air leakage. It should be noted that when a home includes an unheated vestibule or cold porch, the exterior door will be outside the air barrier. In this case, the secondary door between the cold porch and conditioned living space must be air sealed.

Air leaks can be mitigated by removing the interior door trim and caulking between the door frame and the rough opening. Door gaskets and threshold sweeps can also be replaced resulting in home airtightness improvements.

Gaps at door thresholds can be a source of air leakage.



MATERIALS NEEDED

- Polyurethane sealant
  (or low-expansion sprayfoam)
- Closed cell backer rod
- Door gaskets and weatherstripping
- Threshold sweep

RECOMMENDED TOOLS

- Utility knife
- Hammer and nails
- Screwdriver and screws

PROCEDURE

1. Remove interior door trim and threshold and put aside for later reinstallation.
2. Install backer rod and sealant around the door frame perimeter to air seal the door frame. Low-expansion sprayfoam may also be used though may not be as effective as caulking.
3. Remove existing weatherstripping at door jambs and head and replace with new gaskets.
4. Replace existing threshold sweep with an appropriately sized product that is correct for the interior flooring type.

COMPLETE

Note: Consider the size of the gap to be sealed and durability of the product when selecting appropriate weatherstripping.

8.9 Combustion Appliance Vents

Gaps around exhaust vent and chimney penetrations in the ceiling can be a source of air leakage into the attic. Only fireproof sealing materials should be used for air sealing at locations where high temperatures and clearances to combustibles are required. This air sealing approach at the ceiling is completed from within the attic.

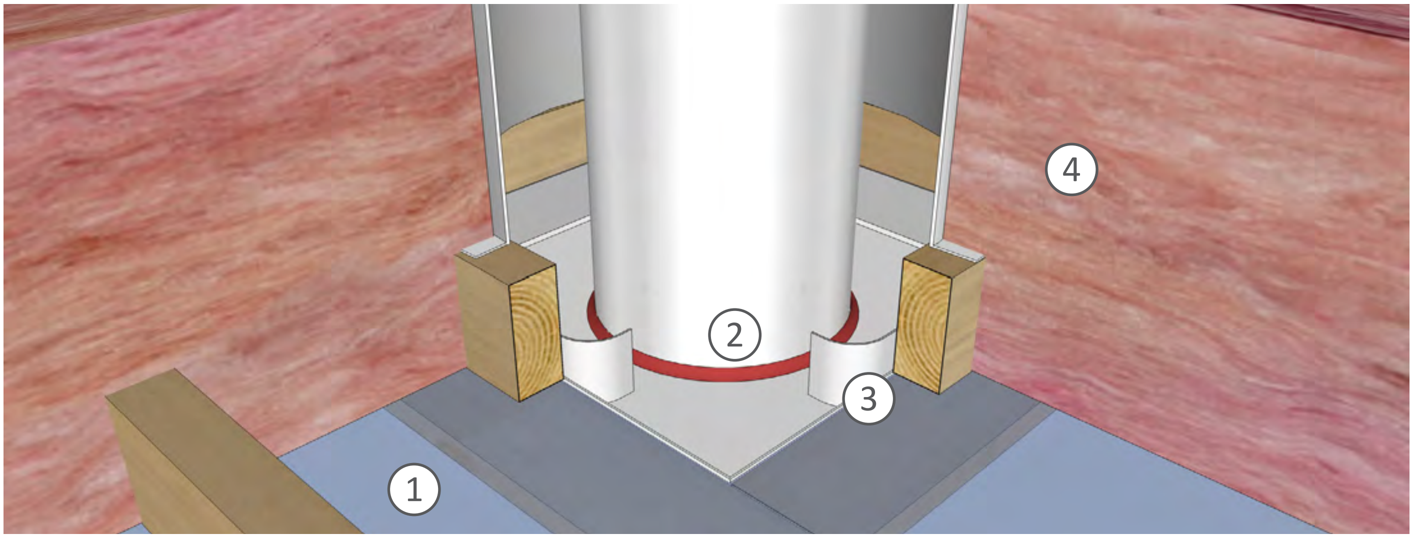
Ducting for combustion appliances including combustion air dampers. See Section 10.0 for more information on mechanical systems.

MATERIALS NEEDED

- Fire-resistant silicone sealant
- Foil tape

RECOMMENDED TOOLS

- Utility knife
- Caulking gun



PROCEDURE

1. Remove surrounding attic insulation and insulation guard at the opening.
2. Apply fire-resistant silicone sealant in a bead around the exhaust vent at the metal ceiling support.
3. Install tape at the perimeter of the opening between the ceiling framing and the ceiling support.
4. Reinstall the insulation guard and insulation. Add new insulation as recommended, ensuring no insulation comes in direct contact with the inner exhaust vent

   COMPLETE

   Note: Ensure there is a minimum 3” clearance around the combustion appliance vent, both at the interior ceiling space and in the attic.

8.10 Plumbing Vent Stack

Ceiling service penetrations can be an overlooked source of air leakage. While many service penetrations occur at the floor beneath the crawlspace, several service penetrations, such as plumbing stacks, may still penetrate through interior walls into the attic space. For this component, the air sealing approach must accommodate the potential thermal movement of the plastic vent pipe while still maintaining air barrier continuity.

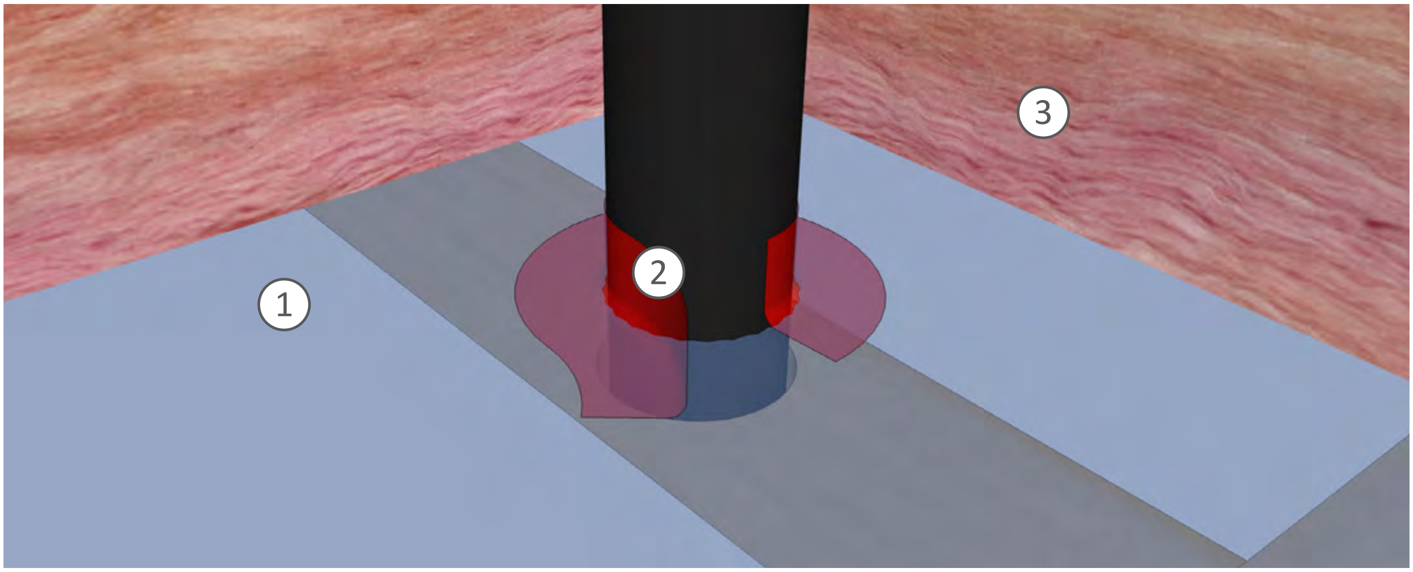
Plumbing vent stack.

MATERIALS NEEDED

- Flexible housewrap tape

RECOMMENDED TOOLS

- Utility knife



PROCEDURE

1. Expose the ceiling polyethylene air barrier around the vent stack. Remove dirt and debris from the surrounding polyethylene and the vent stack.
2. Install flexible housewrap tape around the plumbing vent stack.
3. Reinstall existing insulation.

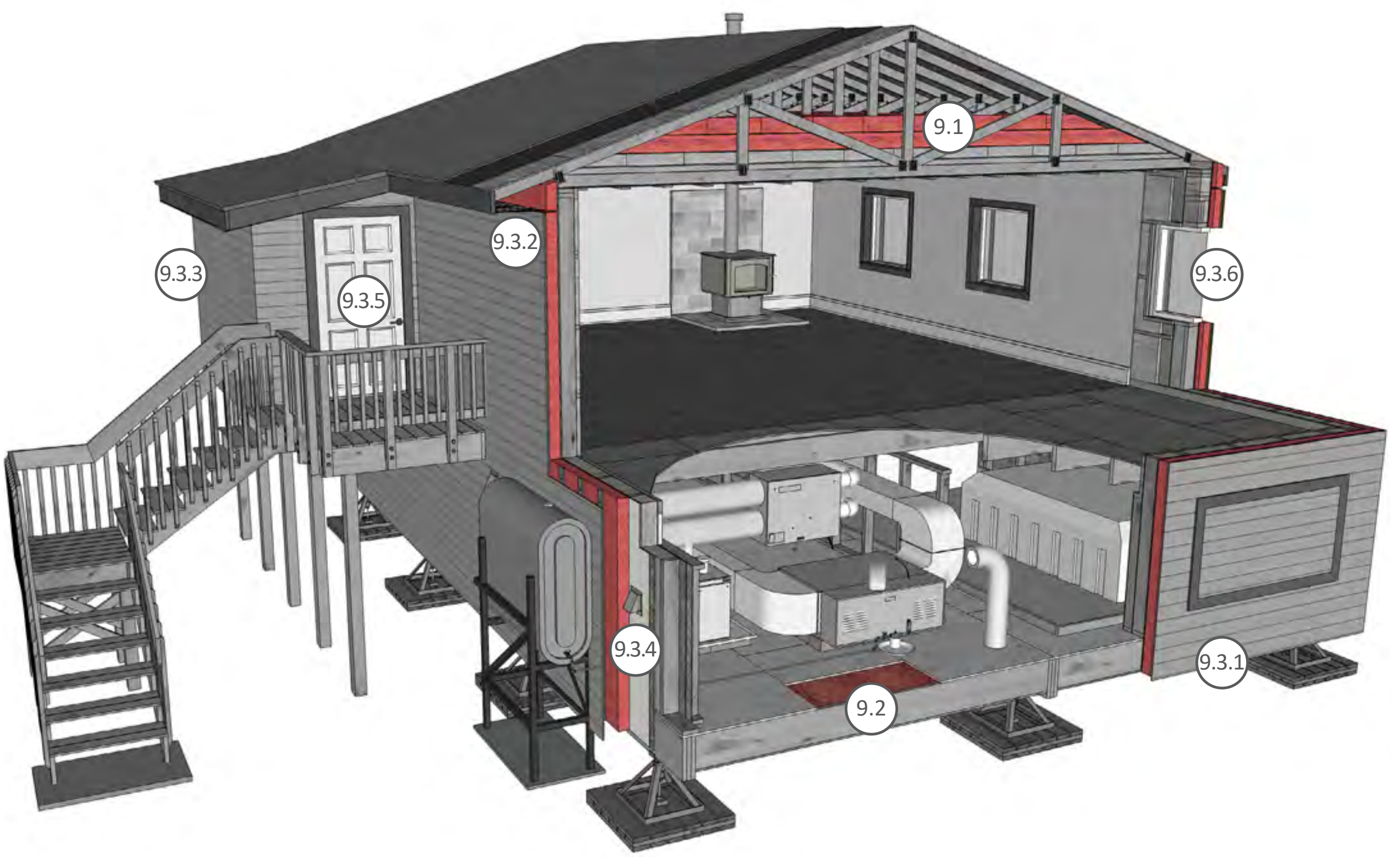
   COMPLETE

   Note: Ensure all ceiling penetrations are air sealed from the attic using a similar approach, being sure to maintain continuity of the air barrier at the polyethylene.

9.0 Insulation Retrofits

Location of Insulation

The following locations indicate where thermal insulation can be added to the building envelope to improve the overall energy performance.



9.1 - ATTIC INSULATION

9.2 - EXPOSED FLOOR INSULATION

9.3.1 - FOUNDATION TO WALL INSULATION

9.3.2 - WALL TO SLOPED ROOF INSULATION

9.3.3 - WALL INSULATION (OUTSIDE CORNER)

9.3.4 - WALL PENETRATIONS

9.3.5 - DOORS

9.3.6. - WINDOWS

9.1 Attic Insulation

Attic Insulation

Adding insulation to the attic space is often a very effective energy-saving measure. However, insulation should only be added in conjunction with air sealing retrofits to decrease the risk of moisture problems that can occur as a result of increased attic insulation levels. There are several important ceiling locations that should be air sealed prior to installing additional insulation in the attic. They include:

- Wall top plates and plumbing/electrical penetrations
- Bathroom fans and ducts
- Kitchen range, dryer, or other exhaust ducts
- Combustion appliance vents (furnace, hot water, wood/pellet stove)

Additional attic insulation together with air sealing measures can have a significant impact on the frequency and severity of ice damming. By reducing the amount of heat flow through the ceiling, the roof sheathing is kept at a lower, more consistent temperature. This reduces the formation of ice dams and, subsequently, improves the overall durability of the building.

It should be noted that it is not always possible to enter the attic from inside the home: in many homes, the attic is accessed through an exterior hatch. Attic access should always be considered when preparing for an attic insulation retrofit.

Insulation Type

If the attic is a simple shape with roof trusses spaced regularly at 16” or 24”, fiberglass or mineral wool batt insulation is recommended as it is easy to install and minimally impacted by wind effects. Be sure to install the insulation so it fits snugly without compression and always follow the manufacturer’s directions to achieve optimal results. It is generally recommended to install two layers of insulation perpendicular to each other with joints staggered.

Blown in insulation is not as effective in the far North due to high winds above the tree line, which increase the potential for movement of the insulation.

Fiberglass batt insulation installed in the attic with baffles included.

Insulation Thickness

Batt insulation installed in the ceiling of the attic will typically have an installed R-value between R-3 and R-4 per inch of thickness depending on the type, manufacturer, and density. Always, consult the product manufacturer’s literature for specific product information. To reach the desired R-value (R-60 to R-80), several layers of insulation will be needed. Each layer should be installed perpendicularly to the previous layer until the desired R-value is met. Note that the insulation thickness will be reduced at the eaves due to the slope of the roof and this will reduce the effective R-value of the ceiling plane. This reduction can typically be partially offset by adding an additional few inches of insulation in the centre, unless the roof slope is particularly shallow.

Ventilation

Attic ventilation is an important factor in controlling moisture in the attic. Poor ventilation, coupled with indoor air leakage is responsible for the majority of attic related moisture and mould problems. Maintaining acceptable attic ventilation levels also reduces ice-damming effects in northern climates.

For attic ventilation to be most effective, outdoor air should enter the attic at the perimeter (soffits) and exit at the attic ridge (ridge or cap vents). The soffit vents can be provided by perforations in the soffit material, discrete vents in the soffit material, or button vents near the typical soffit location. It is critical that soffit vents connect through to the attic and are not obstructed by existing or added insulation. This is typically accomplished by using insulation baffles or guards that are placed between trusses at every or every second bay, depending on the roof configuration.

Extra attention should be paid to the soffit material and vent openings in the North to reduce the amount of blowing snow entering into the attic space.

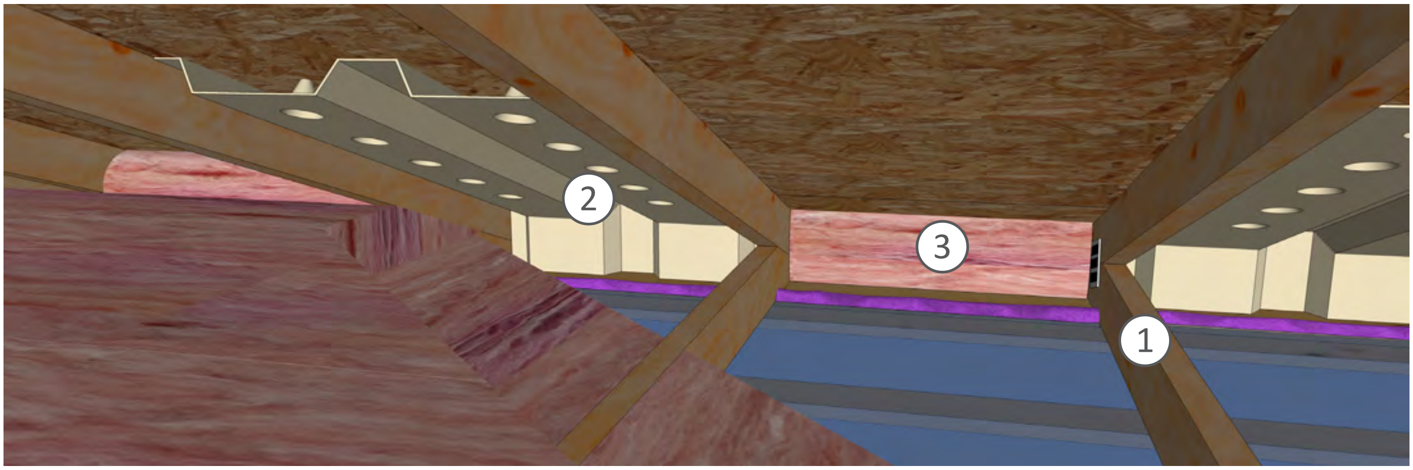
9.1 Attic Insulation

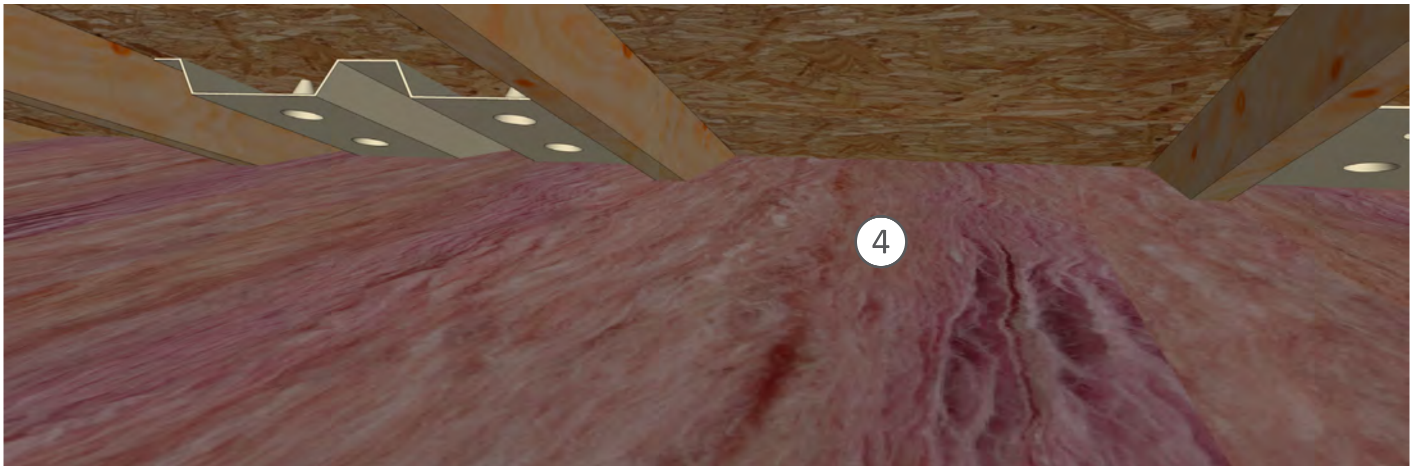
MATERIALS NEEDED

- Fibreglass or mineral fibre batt insulation
- Preformed insulation baffles

RECOMMENDED TOOLS

- Utility knife





PROCEDURE

1. Remove existing insulation and air seal all penetrations into the attic as necessary.
2. Install insulation baffles as required along the roof edge, or above each soffit ventilation port if it is not a continuous soffit vent.
3. Install batt insulation into every empty joist space.
4. Reinstall existing insulation and add new insulation per the manufacturers' instructions. Ensure that each layer of batt insulation is placed perpendicularly to previous layer.

COMPLETE

Note: Ensure that air sealing measures have been undertaken prior to adding new insulation. Batt insulation should form a continuous, non-compressed blanket of insulation when installed properly.

9.2 Exposed Floor Insulation

Floors that are exposed on the underside to outdoor temperatures are common in northern climates. Adding insulation to exposed floors, combined with air sealing retrofits (see earlier discussion on air sealing retrofits), can significantly impact the energy performance of a building. The existing insulation level in the joist space may not fill the space completely, leaving an air space between the installed insulation and the plywood subfloor above. Always check to see if there is room for additional insulation prior to commencing retrofit.

Insulation Type

Blown-in insulation is an economical choice for topping up existing insulation in the floor joist space. Be sure to always follow the manufacturers' installation instructions to achieve optimal results.

The loose material of blown-in fiberglass or cellulose insulation can be installed through small holes in the subfloor and blown throughout the joist space. The subfloor must then be patched and air sealed.

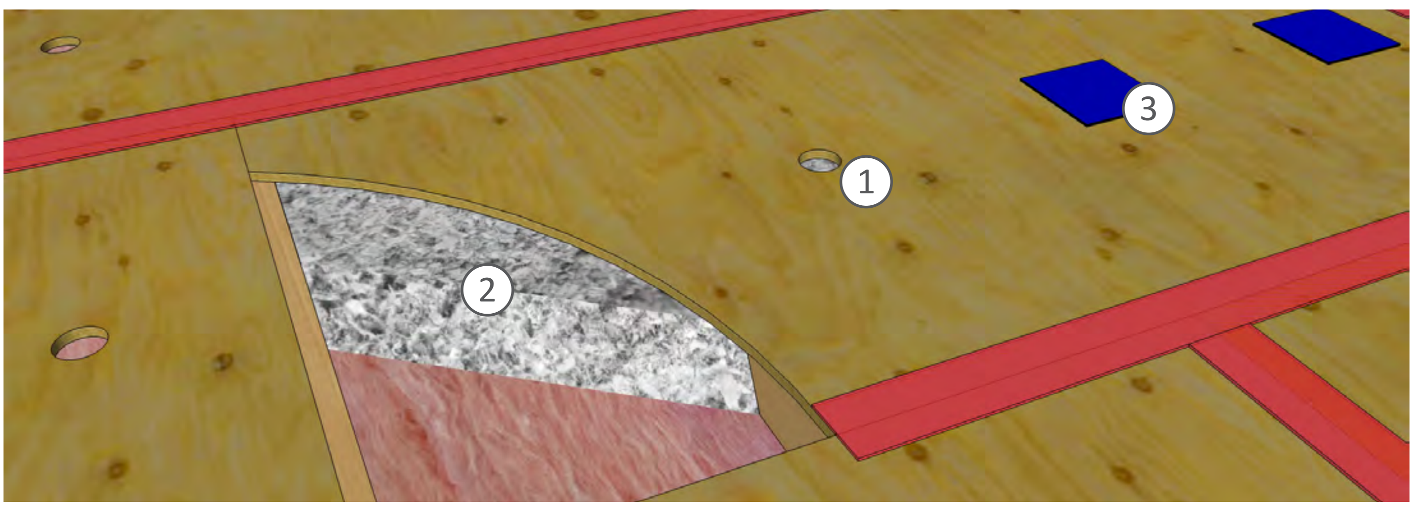
Exposed floor constructed out of OSB sheathing and 1x4 battens. The space between joists is filled with insulation.

MATERIALS NEEDED

- Blown-in fibreglass or cellulose insulation
- Self-adhered membrane

RECOMMENDED TOOLS

- Utility knife
- Drill and hole saw bit



PROCEDURE

1. Drill holes in the plywood subfloor at required locations along the length of the joist space
2. Install blown-in insulation in each joist space.
3. Insert a plug and membrane patch at all holes in the plywood subfloor.

COMPLETE

Note: Ensure the insulation has uniformly filled each joist space. Avoid making holes near existing floor service penetrations and confirm that the floor is airtight to minimize condensation risk within the floor assembly.

9.3 Exterior Wall Insulation Retrofits

Adding additional wall insulation as part of the retrofit plan can significantly reduce energy consumption and heating costs. While major insulation retrofits are generally more expensive, they can have a significant impact on building energy performance.

A major advantage of adding exterior insulation is that insulation can be installed in a single plane without thermal bridging from studs or floor joists. The existing framing and sheathing is also kept warmer, reducing the risk of condensation and moisture damage. For this reason, an exterior insulation retrofit is recommended over an interior insulation retrofit when possible. Note that exterior insulation retrofits require that an exterior insulation attachment strategy be developed in order to secure the insulation and new cladding to the wall. An exterior insulation retrofit is most economical when done in conjunction with other exterior remodeling work (cladding replacement, etc.).

Insulation Type

Exterior insulation can be divided into two categories;

1. vapour-permeable insulations such as semi-rigid or rigid mineral wool, or semi-rigid fiberglass, and
2. relatively vapour-impermeable insulations such as extruded polystyrene (XPS), extruded polystyrene (EPS), polyisocyanurate (polyiso), and closed-cell spray polyurethane foam.

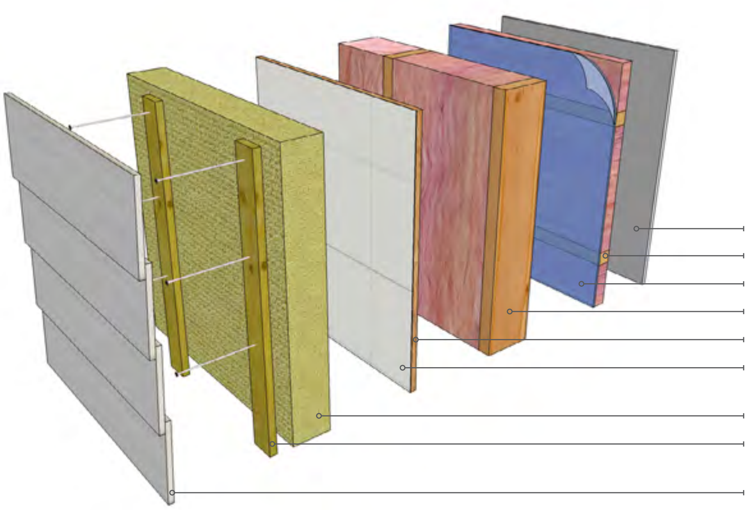
While each of these insulation materials can provide adequate thermal resistance, the vapour permeability of the insulation has important ramifications on the durability of the existing wall assembly. Relatively impermeable foam plastic insulation will not allow moisture in the wall to dry outwards and acts as a vapour retarder. When it is installed in conjunction with an interior vapour retarder (polyethylene sheet) the dual vapour retarders can trap moisture that inadvertently enters the assembly (air leakage, rainwater). This can lead to concealed fungal growth and decay within the wall. Note that vapour-permeable exterior insulation (semi-rigid or rigid mineral wool) is recommended for this energy retrofit because of the above concerns as well as the insulation ratios looked at in this Guide.

Always be sure to install the mineral wool insulation boards tight to adjacent boards and always follow the manufacturers' directions to achieve optimal results.

Air Sealing

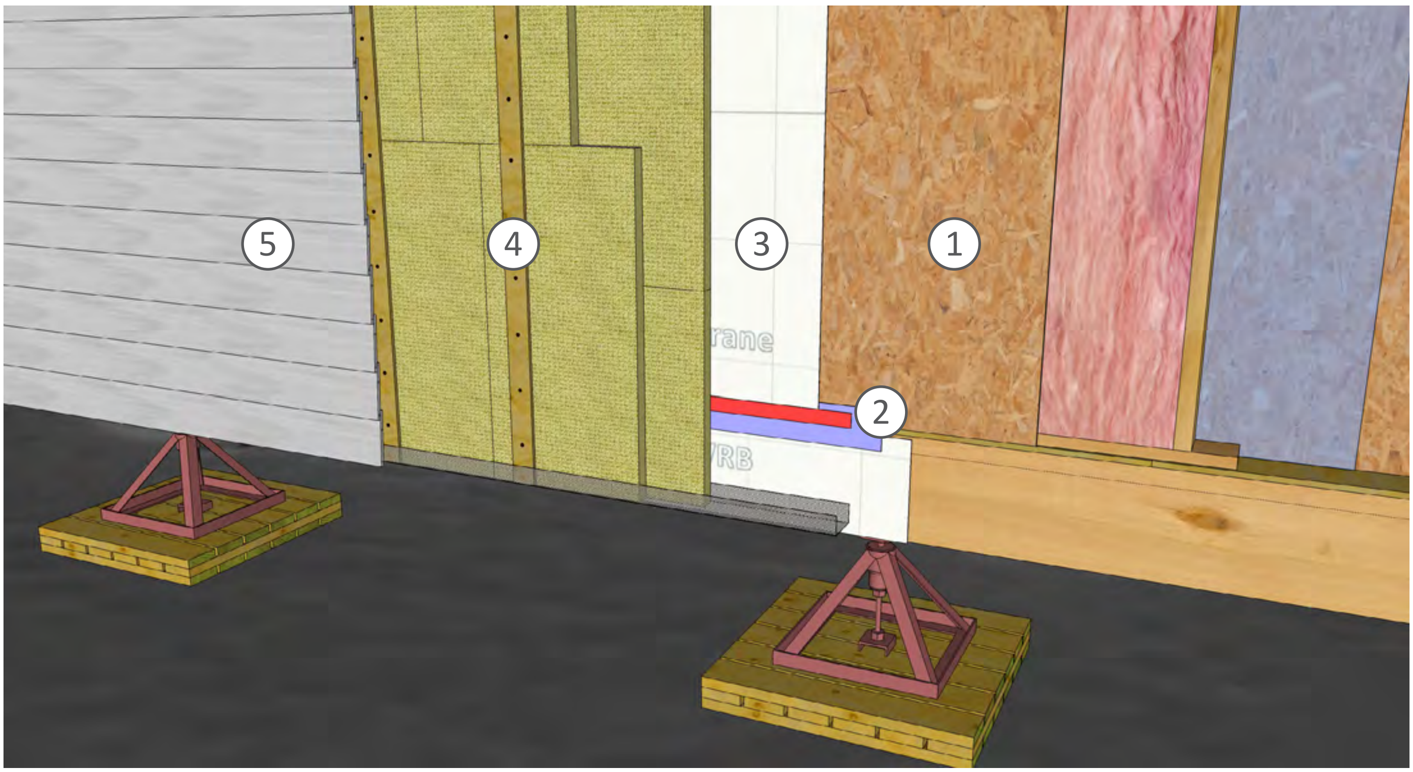
Exterior insulation retrofits provide an opportunity to air seal the building walls from the outside at the existing sheathing plane. The retrofit ensures that a proper air barrier is installed improving overall building airtightness. Air sealing from the exterior is significantly easier and more straightforward than many interior air sealing activities. The exterior air barrier (vapour-permeable sheathing membrane) should be installed on the exterior of the wall behind the insulation with proper membrane detailing at all penetrations and interfaces. A vapour-permeable product should be selected to allow for outward drying and to ensure that moisture is not trapped in the wall assembly. Be sure to consult the membrane manufacturer's instructions and product information prior to installing the new air barrier.

The following pages contain several graphics with guidance on how to detail exterior insulation retrofits.



9.3.1 Foundation to Wall

Air barrier continuity is important at the interface between the foundation and the wall. Special attention must be paid to this transition to ensure that the exterior wall air barrier ties into the floor plane of airtightness. This can be achieved with self-adhered membrane and tape installed at the bottom of the wall framing.

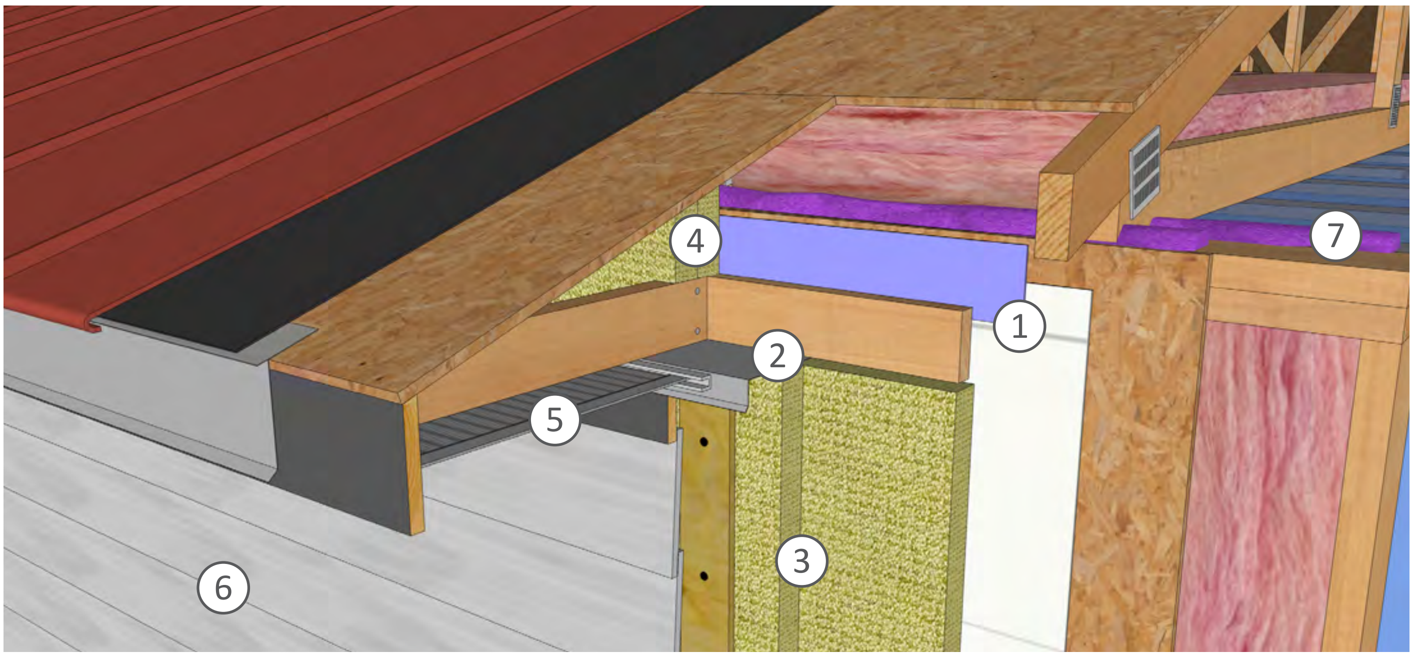


DESIGN CONSIDERATIONS

1. Remove existing siding and building paper to expose exterior wall assembly. Inspect and repair sheathing and framing as necessary.
2. Install self-adhered membrane and seal across to floor sheathing to create air barrier transition.
3. Install vapour-permeable air barrier membrane (mechanically attached sheet or self-adhered) per manufacturer's recommendations. Seal laps and penetrations and tape membrane to the self-adhered membrane air barrier transition at base of wall.
4. Install two layers of 51mm (2") rigid mineral wool insulation. Ensure there are no gaps or voids in the insulation and stagger layers so board joints do not line up. Install borate-treated wood strapping (or plywood) over the exterior insulation aligned with the stud spacing. Secure strapping with long screws through the insulation into the existing sheathing.
5. Install exterior siding and flashings.

9.3.2 Wall to Sloped Roof

Air barrier continuity is important at the interface between the top of the wall and the attic. Special attention must be paid to this transition to ensure that the exterior wall air barrier ties into the ceiling air barrier membrane/plane of airtightness. This can be achieved with self-adhered membrane, sealants, and/or sprayfoam at the top of the wall framing.

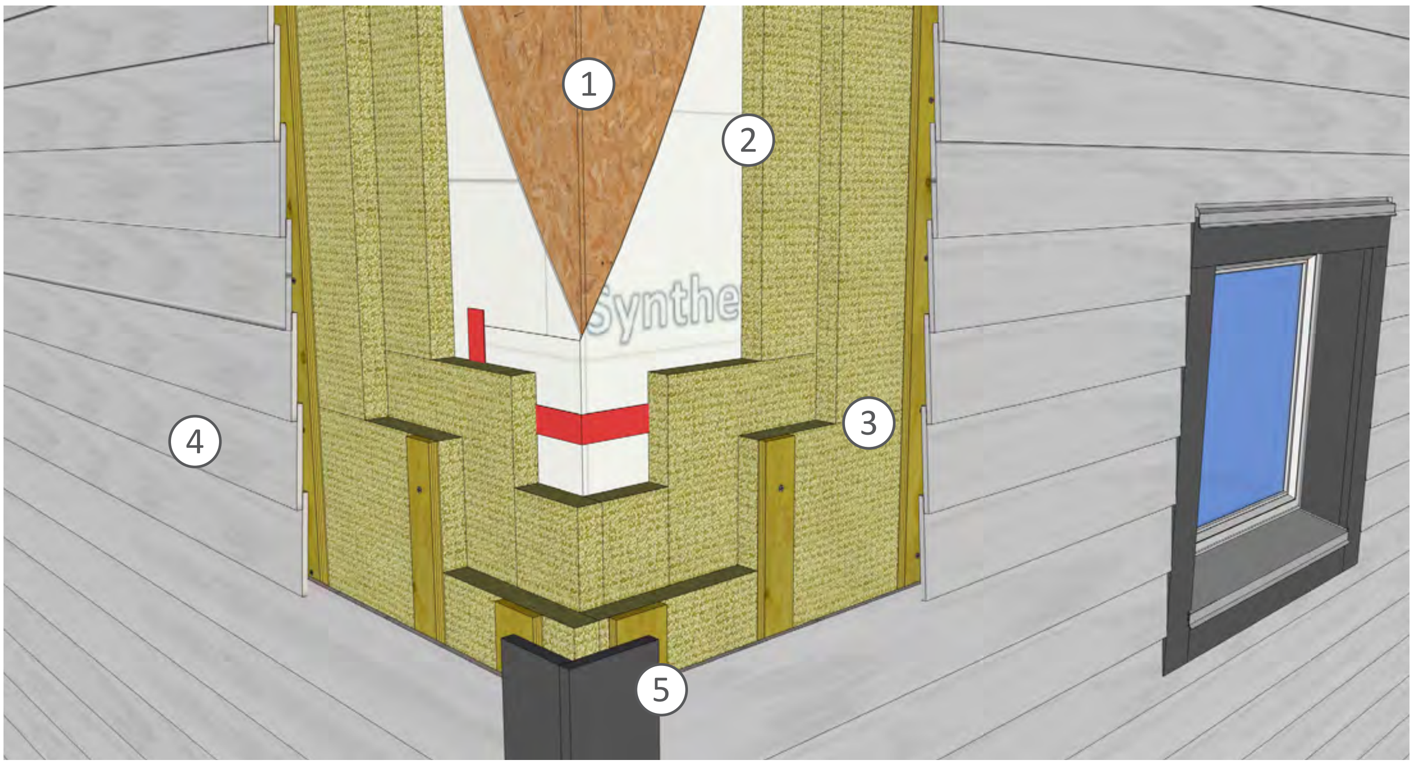


DESIGN CONSIDERATIONS

1. Install vapour-permeable air barrier membrane (mechanically attached sheet or self-adhered) as per manufacturer's recommendations. Seal laps and penetrations and tape membrane to the self-adhered membrane air barrier transition at top of wall.
2. Install closure flashing above the wall insulation and strapping to separate wall cavity from soffit vent intake.
3. Install two layers of 51mm (2") rigid mineral wool insulation. Ensure there are no gaps or voids in the insulation and stagger layers so board joints do not line up. Install borate-treated wood strapping (or plywood) over the exterior insulation aligned with the stud spacing. Secure strapping with long screws through the insulation into the existing sheathing.
4. Place rigid mineral wool insulation at the top of the wall, cut to fit around roof soffit framing.
5. Install perforated panel or ventilation ports at the soffit to provide ventilation into the attic
6. Install exterior siding.
7. Complete exterior insulation work in conjunction with air sealing and insulation work in the ceiling plane. Install sprayfoam between the sheathing and top plate and between the top plate and ceiling polyethylene sheet to transition the air barrier.

9.3.3 Outside Corner

It is important to detail the air barrier membrane properly at building corners. Proper shingling and laps must be provided to seamlessly transition the air barrier across the corner. Wider strapping or plywood strips are generally utilized at the corner to provide additional support for corner trim.

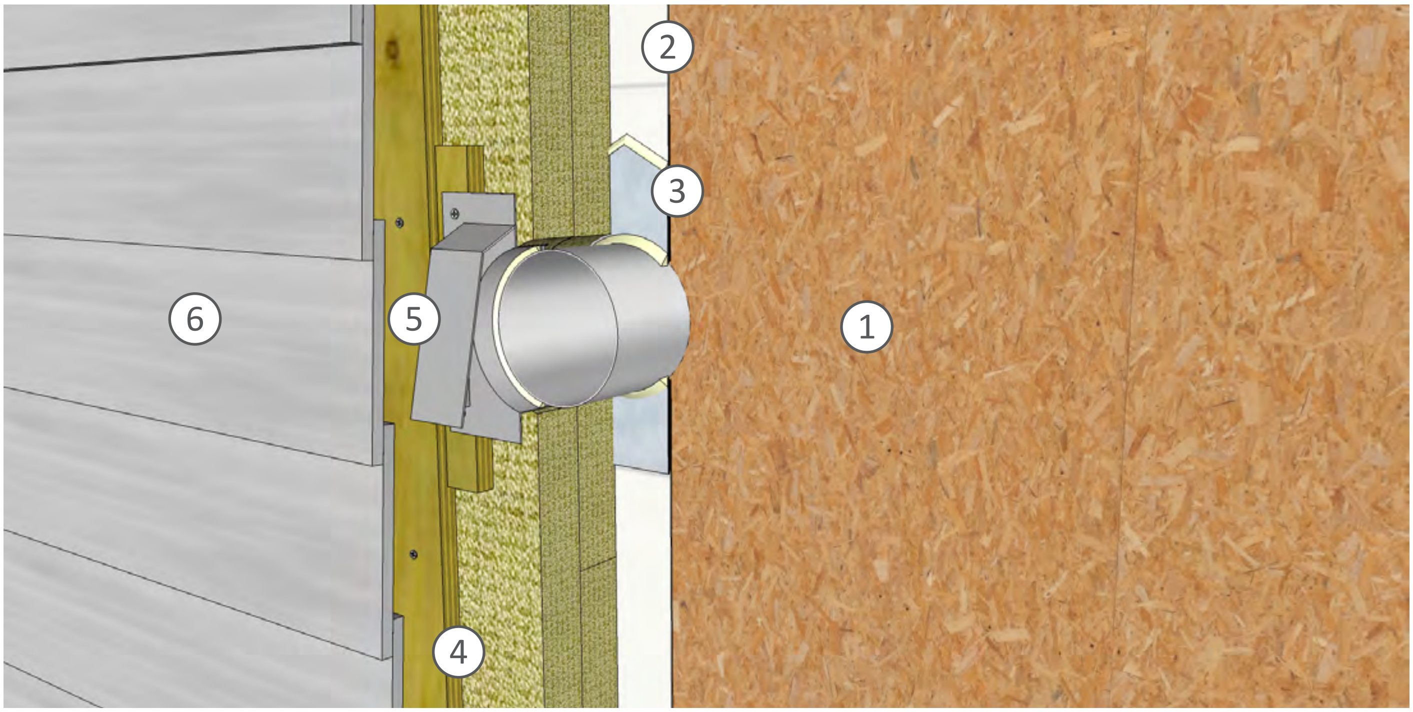


DESIGN CONSIDERATIONS

1. Remove existing siding and building paper to expose exterior wall assembly. Inspect and repair sheathing and framing as necessary.
2. Install vapour-permeable air barrier membrane (mechanically attached sheet or self-adhered) as per manufacturer's recommendations. Extend the membrane around the corner and tape to the adjacent membrane.
3. Install two layers of 51mm (2") rigid mineral wool insulation. Ensure there are no gaps or voids in the insulation and stagger layers so board joints do not line up. Install borate-treated wood strapping (or plywood) over the exterior insulation aligned with the stud spacing. Secure strapping with long screws through the insulation into the existing sheathing. Ensure that strapping provides sufficient support for corner trim.
4. Install exterior siding.
5. Install finish trim at the corner interface.

9.3.4 Wall Penetration

Wall penetrations such as ventilation ducts, fuel lines, and water and sewage hookups should be air sealed from the exterior at the time of the exterior wall retrofit.



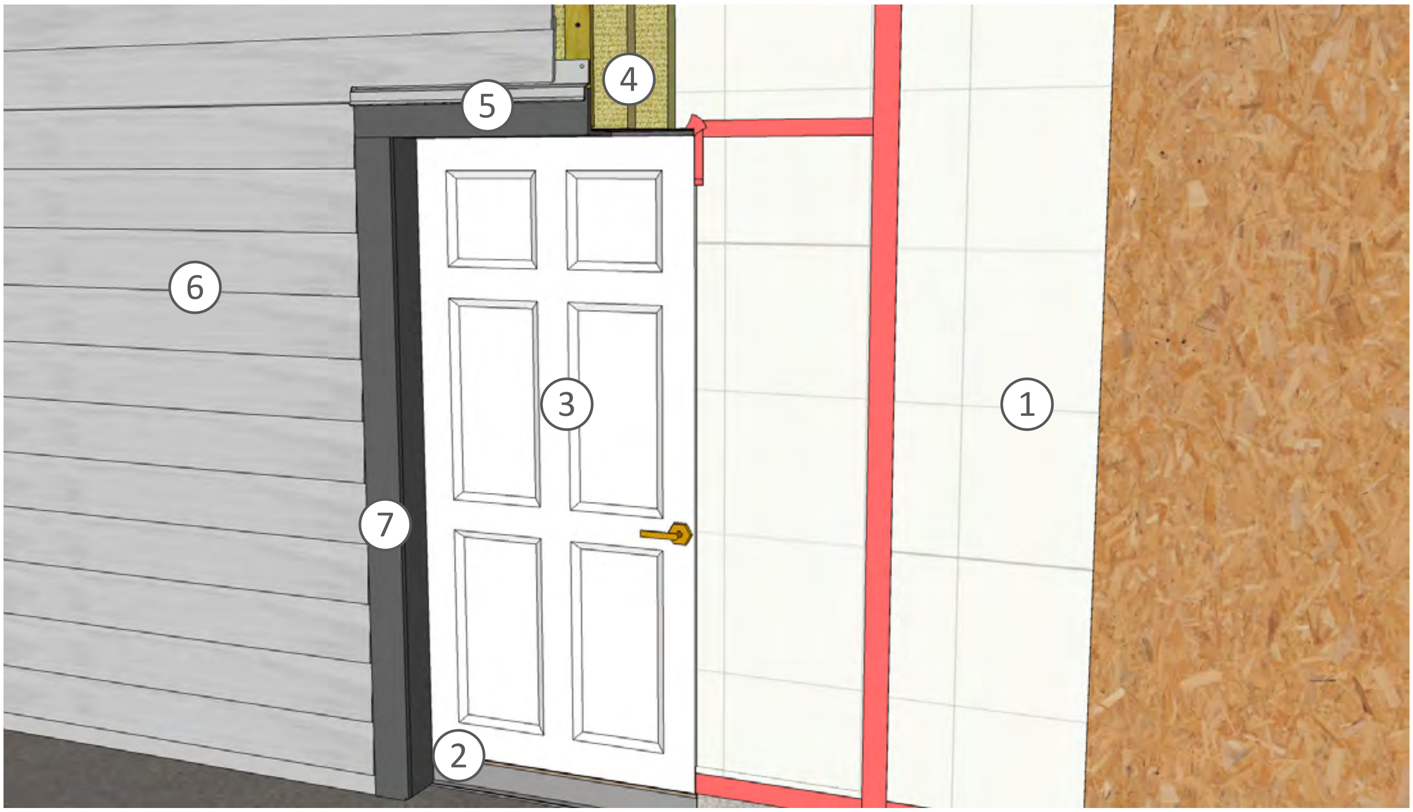
DESIGN CONSIDERATIONS

1. Remove existing siding and building paper to expose exterior wall assembly. Inspect and repair sheathing and framing as necessary.
2. Install vapour-permeable air barrier membrane (mechanically attached sheet or self-adhered) as per manufacturer's recommendations. Seal laps as necessary.
3. Install self-adhered membrane over the air barrier membrane at the duct penetration location. Apply sealant around perimeter of duct penetration to maintain air barrier continuity. Place a bead of sealant along the top edge of self-adhered membrane.
4. Install two layers of 51mm (2") rigid mineral wool insulation. Ensure there are no gaps or voids in the insulation and stagger layers so board joints do not line up. Install borate-treated wood strapping (or plywood) over the exterior insulation aligned with the stud spacing. Secure strapping with long screws through the insulation into the existing sheathing.
5. Install vent hood and secure to support strapping.
6. Install exterior siding.

   Note: Modify detail as necessary where used without exterior insulation.

9.3.5 Door

If exterior doors are being upgraded or replaced during an exterior insulation retrofit, complete the following procedures to address key building science considerations.

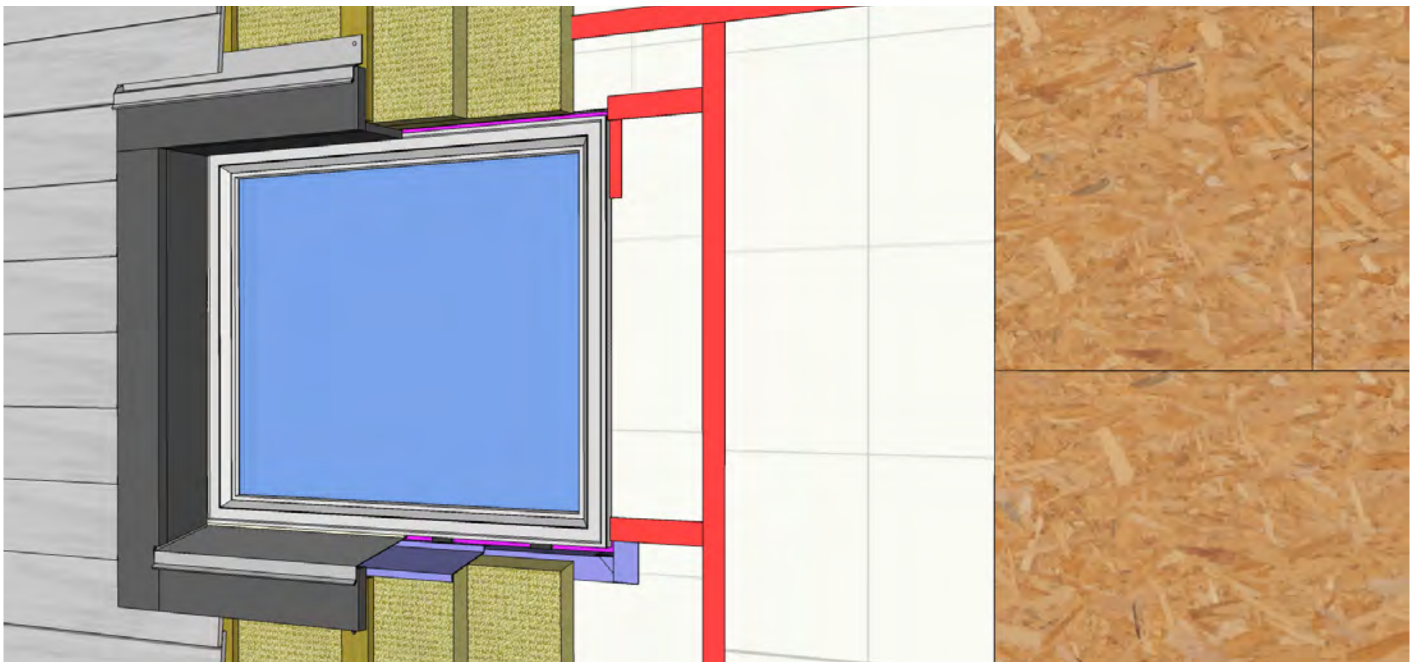


DESIGN CONSIDERATIONS

1. Install vapour-permeable air barrier membrane (mechanically attached sheet or self-adhered) as per manufacturer's recommendations. Seal laps and penetrations and tape membrane to the self-adhered membrane air barrier transition at top of wall.
2. Install sill metal flashing at bottom of door rough opening.
3. Reinstall swing door in rough opening.
4. Install two layers of 51mm (2") rigid mineral wool insulation. Ensure there are no gaps or voids in the insulation and stagger layers so board joints do not line up. Install borate-treated wood strapping (or plywood) over the exterior insulation aligned with the stud spacing. Secure strapping with long screws through the insulation into the existing sheathing.
5. Install metal flashing onto strapping above the door head to deflect moisture out over the door.
6. Install exterior siding.
7. Install finish trim (or cladding returns) where needed to cover the depth of the sides of the exterior insulation on all exposed sides.

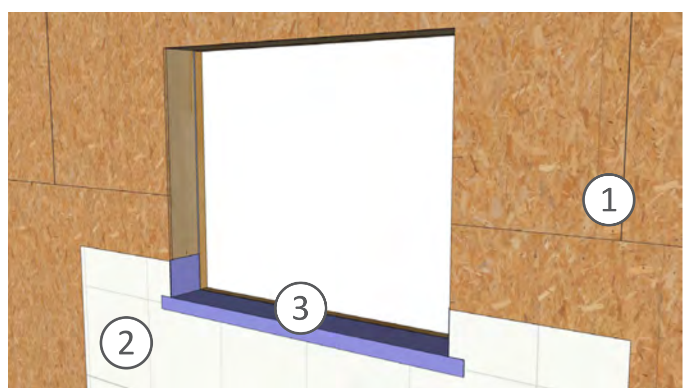
9.3.6 Window

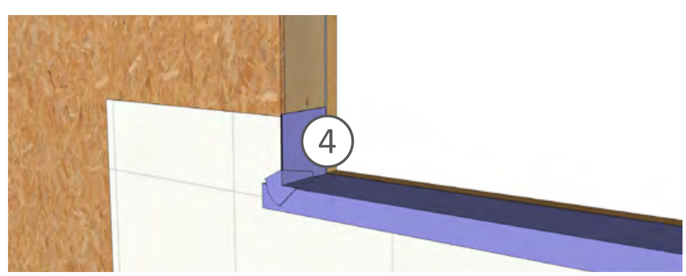
An exterior insulation retrofit is an opportune time to remove existing windows and replace them with more energy-efficient products. The energy-optimized retrofit package involves pairing exterior insulation with a window replacement program. The following building sequence illustrates the proper installation of a new high performance window in a home undergoing a concurrent exterior insulation retrofit.



INSTALLATION SEQUENCE

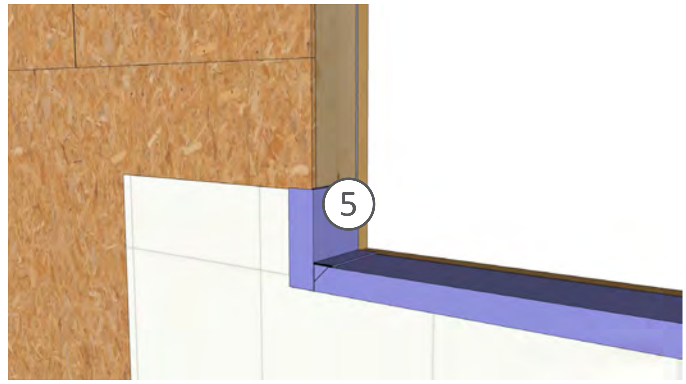
1. Remove existing siding and building paper to expose exterior wall assembly. Inspect and repair sheathing and framing as necessary. Remove the existing window to expose the window rough opening.
2. Install vapour-permeable air barrier membrane (sheathing membrane) starter strip below the rough opening.
3. Install self-adhered sill membrane. Extend membrane up the jambs and onto the face of the wall.
4. Install self-adhered membrane gussets at the lower corners.

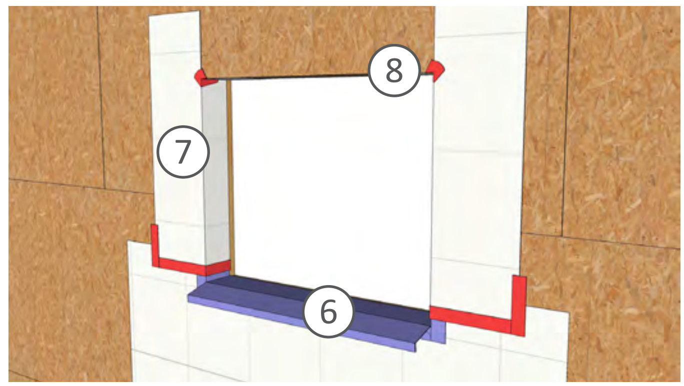


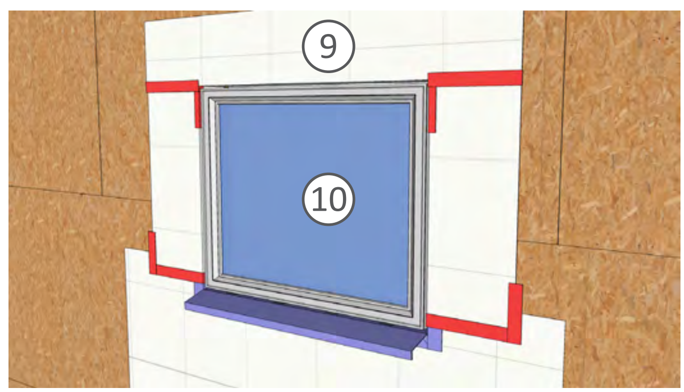


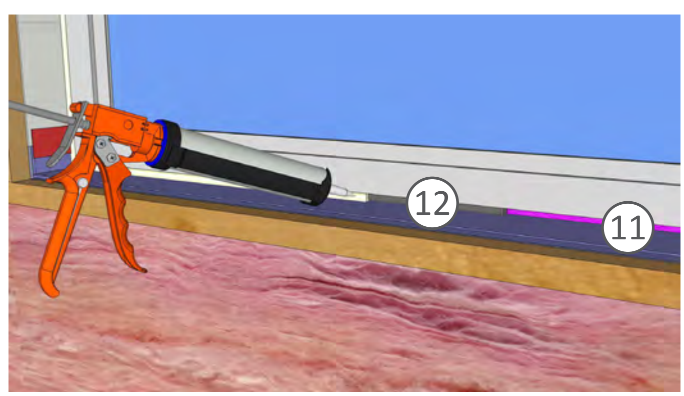
WINDOW INSTALLATION SEQUENCE CONTINUED

5. Install self-adhered membrane at sill corners, extending up the jamb to the height of the sheathing membrane. Finish the self-adhered membrane 2” onto the face of the wall.
6. Install self-adhered skirt membrane to aid in water diversion. Leave backer on unsupported portion of the membrane until after exterior insulation is installed.
7. Install sheathing membrane pre-strips at the jambs and extend onto the wall face a minimum of 8”. Seal all leading edges with sheathing tape.
8. Install sheathing tape gussets at the top corners.
9. Install sheathing membrane at the head of the rough opening, extending a minimum of 12” up the face of the wall. Seal the leading edges with sheathing tape.
10. Set new window on intermittent shims and structurally attach per the window manufacturer’s specifications.
11. Install polyurethane sprayfoam around the interior perimeter of the window.



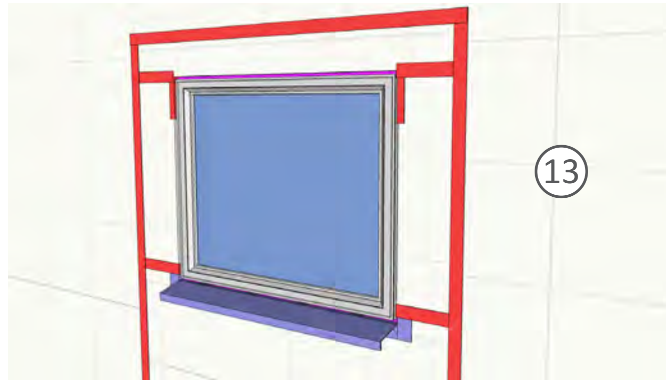


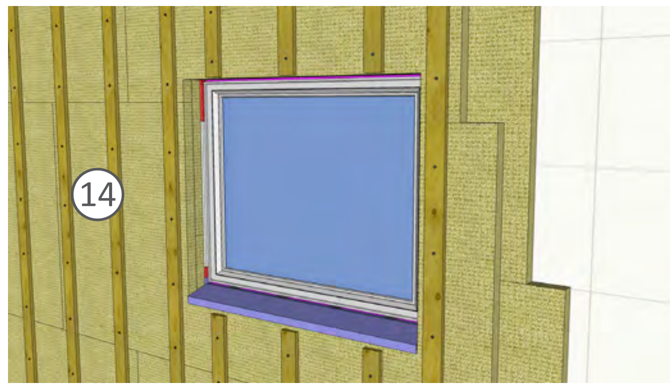


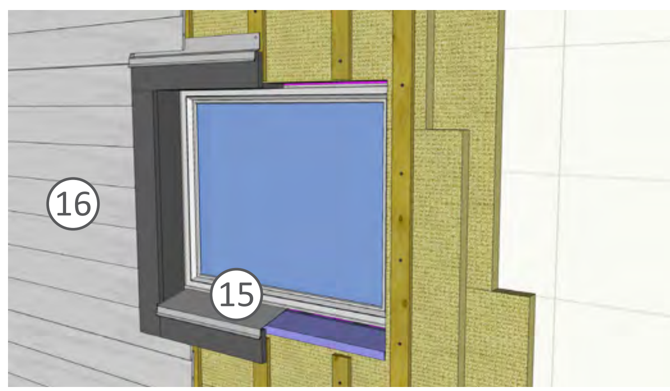


WINDOW INSTALLATION SEQUENCE CONTINUED

12. Install backer rod and sealant around the interior perimeter of the window to complete air barrier continuity.
13. Install sheathing membrane in the field of the wall. Ensure positive laps over all other layers. Seal the leading edges with sheathing tape.
14. Install rigid mineral wool insulation and secure with wood strapping.
15. Install metal head and sill flashing complete with end dams to aid in water diversion away from the window.
16. Install cladding and window trim. Apply sealant around the perimeter of the window between the window frame and window trim boards (top and sides only, leave bottom unsealed for drainage capability).







10.0 Mechanical System Upgrades

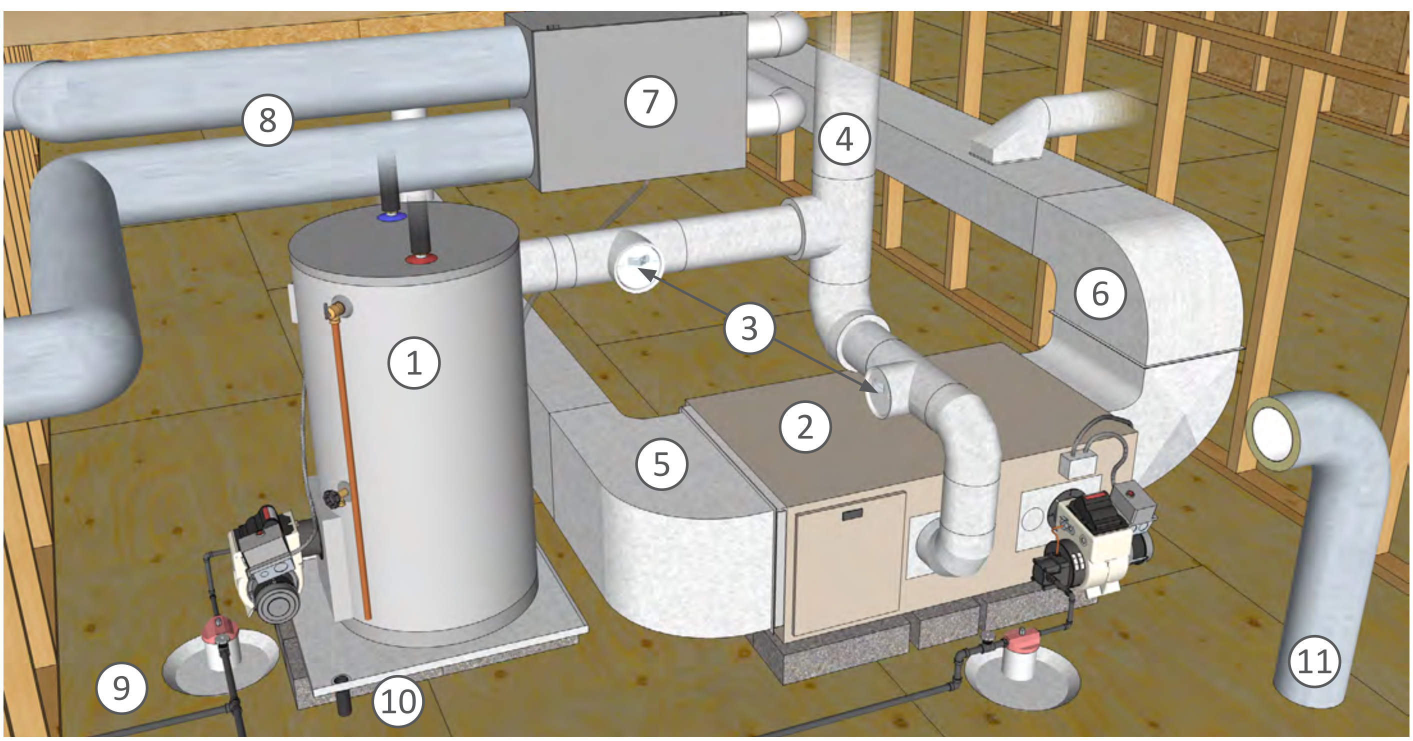
10.1 Existing Systems

The existing mechanical system is most often located down in the crawlspace or a mechanical closet on the main floor, and consists of an oil-fired hot water heater tank, an oil-fired furnace, and in some homes a heat recovery ventilator (HRV). The efficiency of these appliances will have a large impact on the overall energy use of the house. If the mechanical system is to be left in place during the energy retrofit, steps should be taken to ensure the system is tuned-up and running properly and as efficiently as intended, and appropriate air sealing should be completed at all service penetrations.

SYSTEM MAINTENANCE AND AIR SEALING CONSIDERATIONS

1. Existing oil-fired hot water heater with supply to faucets (connection to crawlspace water holding tank not shown)
2. Existing oil-fired furnace (typically ~60% efficiency)
3. Draft or motorized dampers – contractor to adjust as needed and as recommended by water heater and furnace manufacturer
4. Combustion exhaust chimney flue – see 8.9 for air sealing steps
5. Furnace return air plenum
6. Supply air plenum with ducts to main floor above
7. HRV (connected to furnace return air plenum)
8. HRV outdoor air intake and exhaust duct work (insulated)
9. Oil supply line wall penetration – see 8.6 for air sealing steps
10. Hot water heater drain pan and floor penetration
11. Combustion air intake duct (damper not shown) – see 8.5 for air sealing steps

Note: Any work to adjust or modify existing mechanical equipment must be done by an approved HVAC contractor. Refer to the manufacturer's instructions for basic cleaning and maintenance procedures.



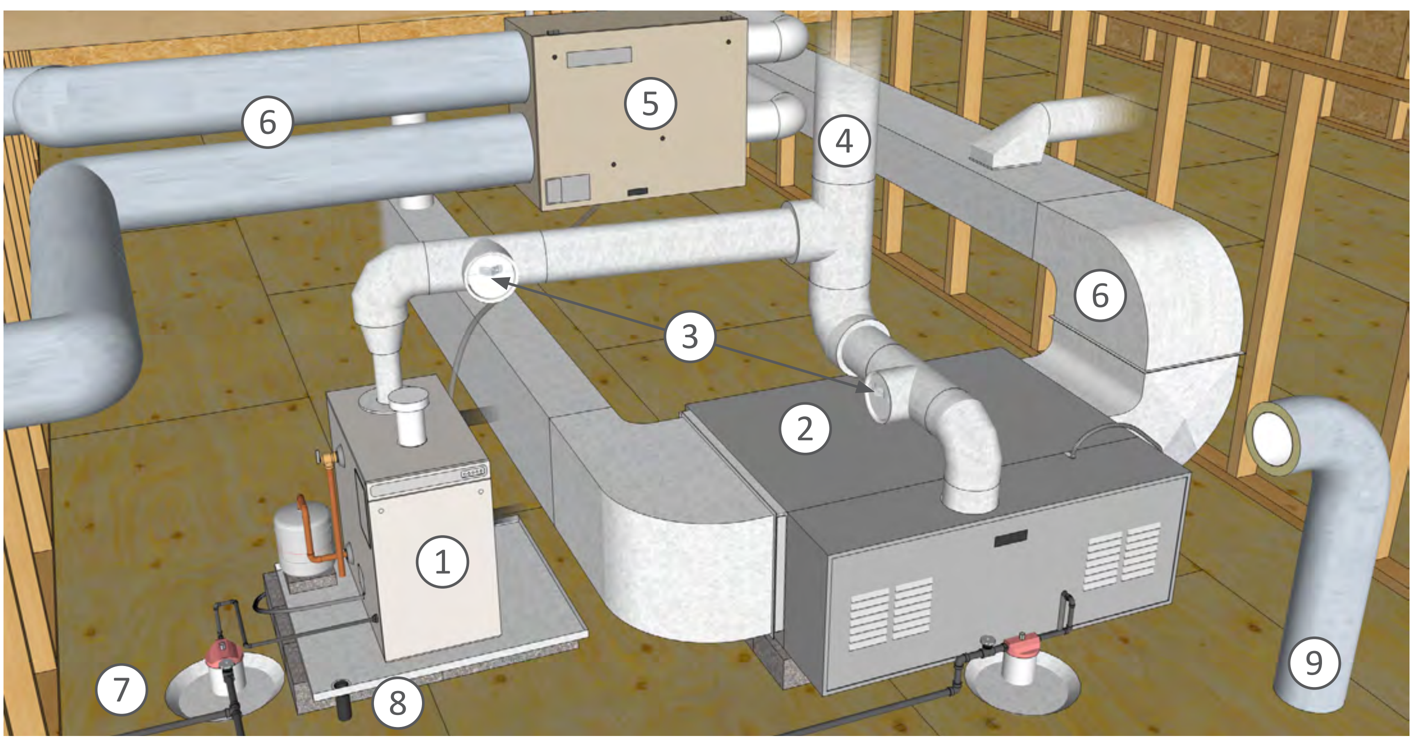
10.2 System Upgrades

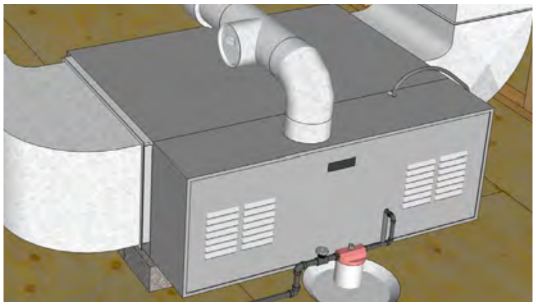
Where mechanical system upgrades are planned as part of the energy-optimized retrofit, each appliance must be carefully selected to ensure it can be installed within the space constraints of the existing mechanical room. Oil-fired burners must have unobstructed exhaust through the existing chimney, and, where applicable, the combustion air intake must be correctly sized and ducted to suit the appliance burner needs. The outdoor air inlet and exhaust outlet for the HRV must be correctly located at the exterior wall to avoid cross-venting, and all appliances that produce condensation or water from pressure relief must be drained to the outside.

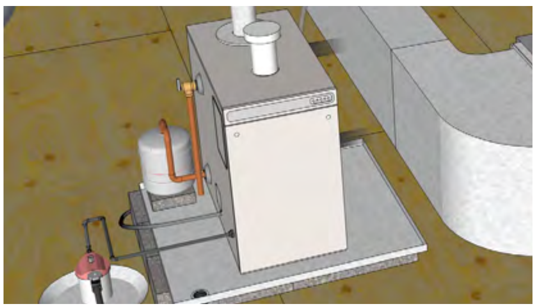
NEW MECHANICAL APPLIANCES

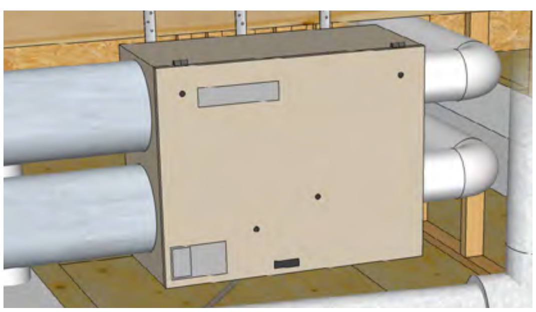
1. New oil-fired on-demand tankless hot water heater (~83% efficiency)
2. New oil-fired furnace (~83% efficiency)
3. Draft or motorized dampers – sized and adjusted as required
4. Combustion exhaust chimney – see 8.9 for air sealing steps
5. New HRV (78% sensible recovery efficiency)
6. HRV air intake and exhaust duct work (insulated) – minimum 1.8m (6') between air inlet and exhaust outlet
7. Oil supply line wall penetration – see 8.6 for air sealing steps
8. Tankless water heater drain pan and floor penetration
9. Combustion air intake duct (damper not shown) – see 8.5 for air sealing steps

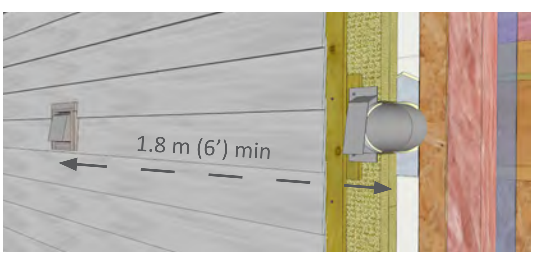
Note: Any work to install or modify existing mechanical equipment must be done by an approved HVAC contractor.











High efficiency furnace

The upgraded oil-fired high efficiency furnace replaces the existing 60% efficiency furnace, and should be listed with an efficiency of approximately 83%. This high efficiency rating is key to ensuring that a reduction in heating costs is achieved. The high efficiency of the furnace comes from various improvements to the heat exchanger, the oil burner, and the insulated furnace enclosure. This means more heat can be produced and less oil is consumed. Note that furnaces with efficiencies higher than 83% are available; however, higher efficiency furnaces will require that the furnace exhaust vent be modified to mitigate the risk of flue gases freezing. Refer to Section 3.0 for more information.

Tankless Water Heater

The tankless hot water heater is a smaller appliance than the traditional hot water tank, since no storage capacity is needed for hot water. The 83% efficient oil burner and heat exchanger simply heats the water as it is being used in a process that produces only the amount of hot water being consumed. This means no excess energy is consumed for the hot water needs of the home, and the energy needed for hot water heating and the associated cost is reduced.

Heat Recovery Ventilator

HRVs are rated by their sensible heat recovery efficiency, which is a measure of how much sensible heat from outgoing air is recovered and transferred to the fresh air. The upgraded heat recovery ventilator (HRV) uses a 78% sensible recovery efficiency (SRE) heat exchanger that transfers heat from outgoing exhaust air to the incoming outdoor fresh air. Stale indoor air is exhausted from the home and passes through the HRV, and fresh outdoor air is directed to the furnace return air plenum where it is further heated and distributed to the bedrooms and living areas with the space heating system. This process saves energy because the incoming outdoor fresh air, which will be cold and must be heated, uses the existing heat energy from the outgoing air for pre-conditioning. As part of the heat recovery process, some condensation may form in the HRV, and must be drained to the exterior. Install the HRV with the condensation drain line secured to the existing hot water pan. At the exterior wall, the HRV exhaust and intake must be located at minimum 1.8 metres (6 feet) apart, to reduce the chances of the intake receiving stale exhaust air. Possible contaminant sources such as the heating oil fuel tank should not be located near the HRV air intake.

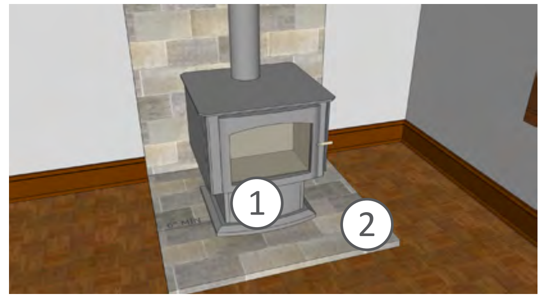
10.3 Wood or Pellet Stove

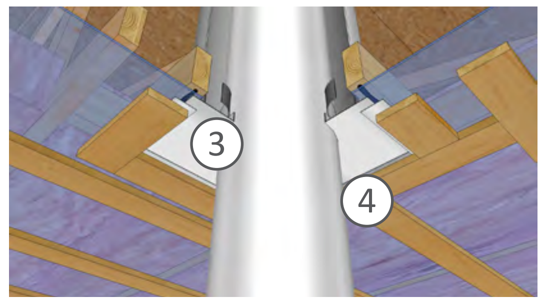
A wood pellet stove can be an economical way to supplement the heating system in the home. The pellet stove uses small wood pieces loaded into a hopper and burned using a conveyor and heat exchanger; the heat is emitted from the vents using a blower fan.

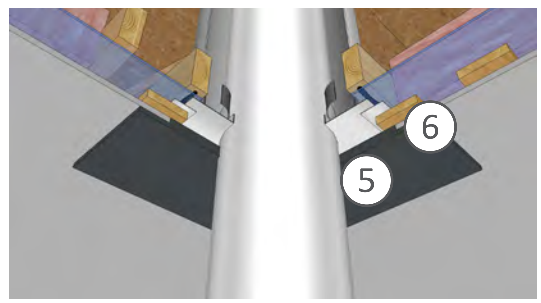
PELLET STOVE INSTALLATION

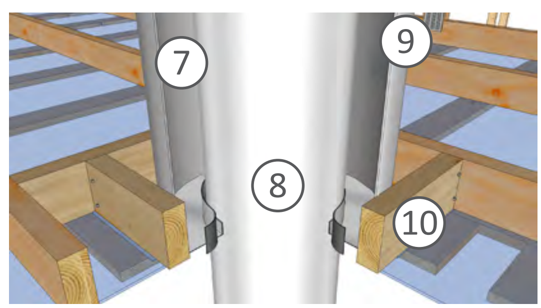
1. Install the pellet stove in a central location in the home to optimize heating efficiency.
2. Install the pellet stove on a tile base and with a backsplash as required for minimum clearances to combustibles.
3. Remove surrounding insulation and cut the ceiling opening for the chimney penetration with the required clearances. Install new chimney support framing and additional strapping at the perimeter of the opening. Note that in some places it is also possible to vent the pellet stove through the wall.
4. Install 3” foil tape at the perimeter of the ceiling opening, lapped a minimum 1” onto the face of the ceiling gypsum board.
5. Attached the chimney support/adapter to the perimeter framing.
6. Run a sealant bead around the perimeter of the chimney support/adapter at the foil tape using fire-resistant silicone sealant.
7. Place the chimney insulation guard over the opening and secure in place.
8. Install the chimney interior and exterior components into the chimney support/adapter.
9. Reinstall previously removed insulation.
10. Place the chimney ceiling trim around the chimney support/adapter to cover the opening and sealant bead.
11. At the exterior roof opening, oversized as required to maintain clearances, install roofing sealant between the top side of the roof building paper and the underside of the roofing around the perimeter of the opening.
12. Install pre-fabricated rubber boot flashing system with a sealant bead at the perimeter on the roof around the fastening ring.
13. Install the metal cover flashing over the rubber boot flashing with a sealant bead around the top perimeter on the chimney.

Note: Consider using a snow splitter installed at the up-slope side of the chimney if the chimney is located towards the roof eave and may be exposed to sliding snow.

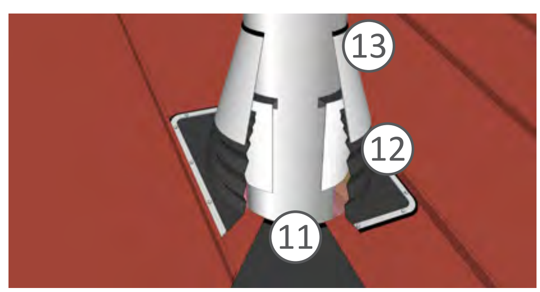








Interior ceiling view

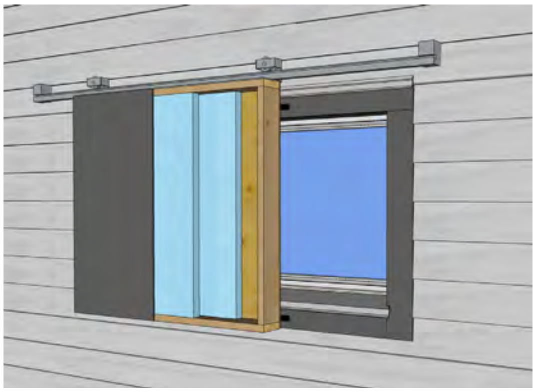


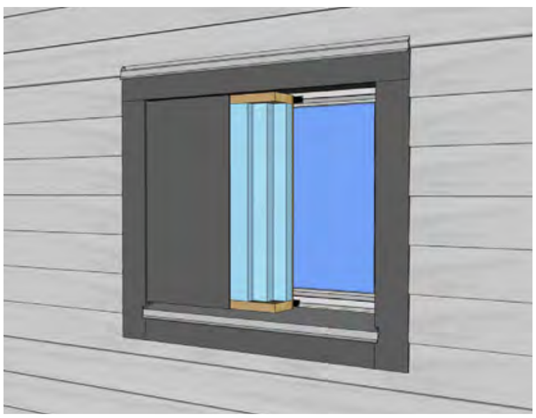
Exterior roof view

Note on Combustion Air Intake Ducts

Many existing mechanical systems rely on passive air inlets to provide supply air for combustion appliances. It is critical that sufficient supply air is provided through these ducts to prevent flue gases from spilling into the living space as a result of building depressurization. By adding a motorized damper to the air intake such that it only opens when the combustion appliance burner is activated, the amount of supply air can be better controlled and building air leakage through these openings can be reduced. It is recommended that a motorized damper system be added to all combustion air intake ducts when an energy retrofit project is being completed.

11.0 Additional Energy Retrofits





Upper | Exterior shutter on a roller track

Centre | Exterior shutter installed plugged in to a recessed window

Lower | Exterior rolling shutter

11.1 Thermal Shutters

In cold climates, windows are a major source of heat loss; however, they are typically very expensive building envelope components to replace. Thermal or insulated window shutters installed during a home retrofit are a small cost saving opportunity when utilized with existing windows. Thermal shutters should be movable, so windows can take advantage of solar gains when the sun is shining, but provide additional insulation during cold winter nights. Generally, shutter insulation values between R-1 and R-5 greatly reduce window heat loss, with diminishing returns as the insulation increases above R-5[2]. This indicates that even a limited amount of shutter insulation can have a significant impact on building enclosure performance.

When installing shutters, consideration for egress should be made for windows that must be operable during emergencies (i.e., bedroom windows). As a result, shutter installation may be limited to fixed windows under most circumstances.

Exterior Shutters

Exterior shutters can be site-built out of plywood, framing lumber, and rigid foam insulation such as extruded polystyrene. While exterior shutters are not airtight, perimeter brushes and/or gaskets can be installed on the back side of the assembly to limit air movement at the window face reducing heat loss. It should be noted that exterior shutters do not need to be perfectly airtight in order to reduce heat loss and improve the overall condensation resistance of the window.

The assembly can be attached to a roller track anchored to the building to allow the assembly to be easily opened and closed. It can also be installed as a plug in a recessed window secured with metal angles and fasteners. Both options are shown in the graphics at left.

Exterior Rolling Shutters

An exterior roller shutter assembly is generally procured as a complete unit that is installed on the exterior of the window. The shutters are composed of many insulated slats that can be rolled/unrolled like blinds; however, they are typically thin and do not provide the same insulation benefit as exterior shutters. Exterior rolling shutters are often designed to be remotely controlled, which improves their utility and when shut they reduce air movement at the window face.

[2] *Evaluating Window Insulation published by Cold Climate Housing Research Center*

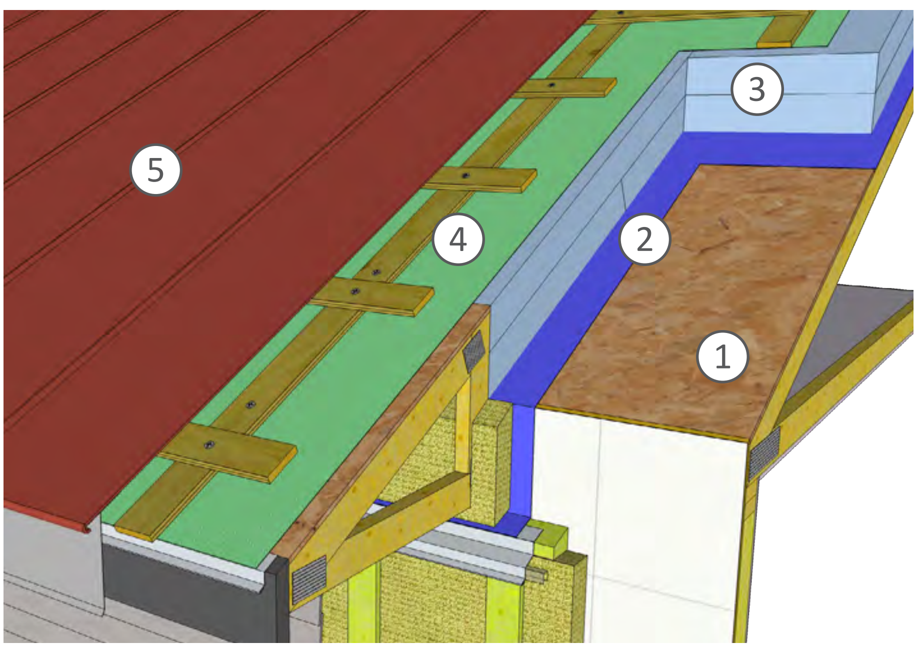
11.2 Arctic Hot Roof

Buildings in the North are regularly exposed to severe environmental conditions including snow, wind, rain, and large temperature swings. While conventional vented roofing assemblies can perform adequately in the North, a properly designed arctic hot roof can substantially improve building durability and energy performance.

An arctic hot roof is an inverted roof assembly where a continuous waterproofing membrane is installed over the roof deck with insulation installed outboard of the membrane. A roof underlayment is then provided above the insulation as a water-shedding weather barrier to remove moisture that penetrates the metal roofing.

There are several technical advantages to installing an arctic hot roof as part of an energy retrofit process. Thermal bridging is reduced by installing insulation outboard of the wood trusses and joists. Air sealing from the exterior is also simpler with fewer penetrations to accommodate, compared to air sealing in the ceiling plane. Additionally, exterior insulation increases the temperature of the sheathing and framing, which reduces the potential for condensation and associated damage.

Good design and workmanship are critical when designing and constructing an arctic hot roof. If the additional weight of materials outboard of the roof sheathing is not considered, the roof assembly may fail structurally. It can also be difficult to maintain air barrier continuity: the air barrier must effectively bridge between the underside of the roof deck and the top of the wall. Sprayfoam or other sealing methods can be used in conjunction with foam blocking installed between roof trusses to accomplish this air barrier transition.



1. *Roof deck*
2. *Continuous air and moisture barrier*
3. *Rigid insulation*
4. *Underlay and strapping*
5. *Metal roof*

12.0 Other Assemblies Not Discussed

12.1 Exposed Floor With No Crawlspace

The building archetype described in this Guide includes a heated crawlspace where mechanical equipment along with water and sewer tanks are located. The crawlspace acts as a thermal buffer between the exterior environment and the living space, reducing the likelihood of occupant discomfort.

However, many northern homes are constructed with a single, suspended floor system, lying directly over the exterior environment. Generally, this has negative implications on occupant comfort as the floor will be colder than if a crawlspace were present.

If uninsulated, occupant comfort can be improved by air sealing the floor and installing insulation in the floor joist cavities. Comfort can also be improved in some circumstances by leaving a small air space between the insulation and the subflooring in order to create a small thermal buffer. However, it is essential that the floor system be completely air sealed on both sides for this strategy to be successful. In practice, it may be better to completely fill the floor joist cavities with insulation as any air leaks in the floor assembly will allow cold air to infiltrate the floor joist bays and bypass the insulation, negating any benefits of the air space.

13.0 Additional Resources

Weatherization and Builders' Construction Guides

A Homeowner's Guide to Permafrost in Nunavut. 2013. Government of Nunavut. Available online:
http://climatechangenunavut.ca/sites/default/files/permafrost_nunavut_eng_reduced_size_0.pdf

Air Leakage Control Manual for Existing Multi-Unit Residential Buildings. 2007. Canada Mortgage and Housing Corporation. Available online:
http://publications.gc.ca/collections/collection_2015/schl-cmhc/NH15-434-2007-eng.pdf

Air Sealing Homes for Energy Conservation. 1984. Energy, Mines, and Resources Canada. Prepared by Marbek Resource Consultants.

Alaska Residential Building Manual. 2007. Alaska Housing Finance Corporation. Available online:
https://www.ahfc.us/files/2813/5716/1325/building_manual.pdf

Building in the North. 1996. Cold Climate Housing Research Center. Available online:
https://www.uaa.alaska.edu/civilengineering/arctic/upload/Building_in_the_North.pdf

Canadian Home Builder's Association Builder's Manual. 2013. Canadian Home Builder's Association. Available online:
www.chba.ca/buildermanual.aspx

Energy Efficient Housing Guidelines for Whitehorse, YT – Energy Optimized House. 2015. Natural Resources Canada. Available online:
http://www.energy.gov.yk.ca/pdf/Energy-Efficient-Northern-Housing-Guide-Energy-Optimized.pdf

Evaluating Window Insulation. 2011. Cold Climate Housing Research Center. Available online:
http://www.cchrc.org/sites/default/files/docs/window_insulation_final.pdf

Good Building Practices Guideline. 2005. Government of Nunavut. Available online:
http://cgs.gov.nu.ca/PDF/Good%20Building%20Practices%20Guideline.pdf

Keeping the Heat In. 2012. Natural Resources Canada. Available online:
https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/housing/Keeping-the-Heat-In_e.pdf

Safe, Effective, & Affordable Retrofits. 2015. Cold Climate Research Center. Available online:
http://www.cchrc.org/sites/default/files/docs/SafeAffordableRetrofits.pdf

Health and Safety

Asbestos Hazards

Asbestos Abatement. 2012. Worker's Safety & Compensation Commission. Available online: http://www.wscc.nt.ca/sites/default/files/documents/Asbestos%20Abatement%20Code%2020%20English.pdf

Environmental Guideline for Waste Asbestos. 2011. Government of Nunavut. Available online:
http://gov.nu.ca/sites/default/files/waste_asbestos_2011.pdf

General Guidelines – Asbestos Removal and Disposal. 2010. Government of the Northwest Territories. Available online:
http://www.pws.gov.nt.ca/pdf/publications/Asbestos%20Removal%20and%20Disposal%20Guidelines%202010.pdf

Guideline for the Management of Waste Asbestos. 2004. Government of the Northwest Territories. Available online:
http://www.enr.gov.nt.ca/sites/default/files/guidelines/asbestos.pdf

Home Ventilation

Heat Recovery Ventilators. 2012. Natural Resources Canada. Available online:
http://www.housing.yk.ca/pdf/hrv.pdf

Residential Mechanical Ventilation Systems Manual. 2006. The Heating, Refrigeration and Air Conditioning Institute of Canada. Available online:
http://www.hrai.ca

Lead Paint

Guideline for the Management of Waste Lead and Lead Paint. 2004. Government of the Northwest Territories. Available online:
http://www.enr.gov.nt.ca/sites/default/files/guidelines/guideline_waste_lead_and_paint.pdf

Mould, Fungal Growth, and Moisture Damage

Guidelines on Assessment and Remediation of Fungi in Indoor Environments. 2008. New York City Department of Health and Mental Hygiene. Available online:
http://www.nyc.gov/html/doh/downloads/pdf/epi/epi-mold-guidelines.pdf

Mould Guidelines for the Canadian Construction Industry. 2004. Canadian Construction Association. Available online:
http://www.cca-acc.com/documents/cca82/cca82.pdf

Safety & Care – Mould Removal. 2015. Worker's Safety & Compensation Commission.
Available online:

http://www.wscc.nt.ca/sites/default/files/documents/Mould%20Removal%20English.pdf