Illustrated Guide R30+ Effective Vaulted & Flat Roofs in Residential Construction in British Columbia

British Columbia

BC HOUSING
RESEARCH CENTRE

BC HOUSING
RESEARCH CENTRE

BC Housing's Research Centre works in collaboration with housing sector partners to foster excellence in residential construction and find innovative solutions for affordable housing in British Columbia. Sharing leading-edge research, advances in building science, and new technologies encourages best practice. The Research Centre identifies and bridges research gaps to address homelessness, housing affordability, social housing challenges and the needs of distinct populations. Mobilizing knowledge and research expertise helps improve the quality of housing and leads to innovation and adoption of new construction techniques, Building Code changes, and enhanced education and training programs. Learn more about the Research Centre at www.bchousing.org. Sign up to receive the latest news and updates at www.bchousing.org/subscribe.

BC Housing
1701 – 4555 Kingsway
Burnaby, British Columbia V5H 4V8
Canada

To purchase printed copies of this guide, order online at: www.crownpub.bc.ca
Product/Material No: 7680003588

For more information contact:
Crown Publications, Queen's Printer
Toll Free: 1 800 663-6105
Email: crownpub@gov.bc.ca

BRITISH COLUMBIA
QUEEN'S PRINTER
PUBLICATION SERVICES
A BRANCH of SHARED SERVICES BC

This guide was funded by BC Housing, the City of Vancouver, the City of New Westminster, the Canadian Wood Council, the Roofing Contractors Association of BC, and the Forestry Innovation Investment, and was prepared by RDH Building Science and Morrison Hershfield. Acknowledgment is extended to all those who participated in this project as part of the project team or as external reviewers.

Authors

Christopher Marleau | James Higgins | Lorne Ricketts (RDH Building Science Inc.)
Patrick Roppel (Morrison Hershfield)

External Reviewers & Contributors

Maura Gatensby - Architectural Institute of British Columbia
Ralph Moore - Aviva
Remi Charron - BC Housing
Cindy Moran - BC Housing
Denisa Ionescu - BC Housing
Jim Baker - Building and Safety Standards Branch
Robert Jonkman - Canadian Wood Council
Norm Connolly - City of New Westminster
Chris Higgins - City of Vancouver
Paul Weber - City of Vancouver
Boris Turishev - City of Vancouver
Antje Wahl - Forestry Innovation Investment
Opreet Kang - Forestry Innovation Investment
Richard Kadulski - Richard Kadulski Architect
Laurence Matzek - Roofing Contractors Association of BC
Don Munich - Travelers Canada
Sukh Johal - Wood Works BC

Disclaimer

This guide is provided for general information only except where noted. The greatest care has been taken to confirm the accuracy of the information contained herein; however, the authors, funders, publisher, and other contributors assume no liability for any damage, injury, loss, or expense that may be incurred or suffered as a result of the use of this publication, including products, building techniques, or practices. The views expressed herein do not necessarily represent those of any individual contributor.

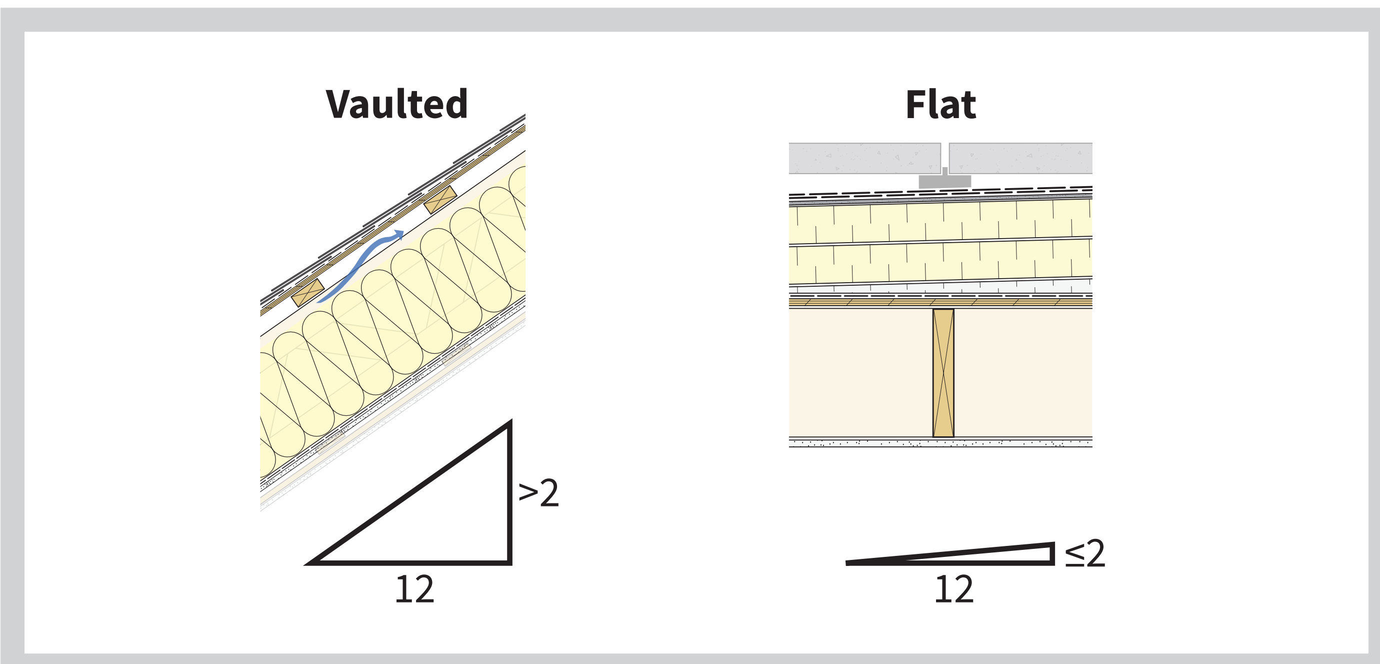
Building products and construction practices change and improve over time, and it is advisable to regularly consult up-to-date technical publications rather than relying solely on this publication. It is also advisable to seek specific information on the use of products, the requirements of good design and construction practices, and requirements of the applicable building codes before undertaking a construction project. Consult the manufacturer's instructions for construction products, and also speak with and retain consultants with appropriate engineering or architectural qualifications, and appropriate municipal and other authorities, regarding issues of design and construction practices. Most provisions of the building codes (British Columbia Building Code and the Vancouver Building Bylaw) have not been specifically referenced, and use of the guide does not guarantee compliance with code requirements, nor does the use of systems not covered by this guide preclude compliance. Always review and comply with the specific requirements of the applicable building codes for each construction project. The materials and colours shown as examples in the guide are not intended to represent any specific brands or products, and it is acknowledged that many product options exist.

About this Guide

This Illustrated Guide consolidates information on vaulted water-shedding roofs and flat waterproof membrane roofs that are capable of meeting R-30 or greater effective thermal performance when used on low- and mid-rise wood-frame buildings. This level of thermal performance is becoming necessary as part of energy performance improvements required by the BC Energy Step Code and the Vancouver Building Bylaw. The guide is intended to be an industry, utility, and government resource with respect to meeting this thermal performance level, while not compromising other aspects of building enclosure performance, including moisture management, air leakage, and durability.

The information included in this guide applies to vaulted and flat (i.e., non-attic) wood-frame roofs in British Columbia. A vaulted roof (also referred to as a cathedral roof) is defined as a roof with a slope greater than 2:12, whereas a flat roof (i.e., low-slope) has a slope that is equal to or less than 2:12. Attic and non-wood-frame roof assemblies are beyond the scope of this guide.

It is important to note that each building and construction project is different and presents unique challenges and considerations. This guide presents an overview of potentially applicable assemblies to meet higher thermal performance targets, but it is likely that these methods will need to be modified to accommodate variations in each project. It is recognized that alternative assemblies exist beyond the scope of this guide.



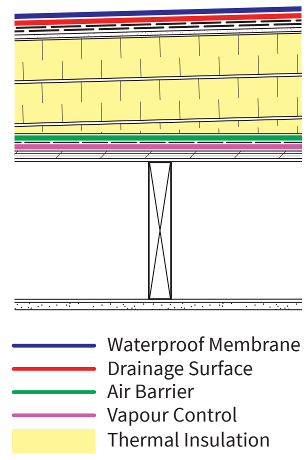
Building Enclosure Overview

The building enclosure is a system of materials, components, and assemblies that physically separate the exterior and interior environments. It comprises various elements including roofs, above-grade walls, windows, doors, skylights, below-grade walls, and floors, which in combination must control water, air, heat, water vapour, fire, smoke, and sound.

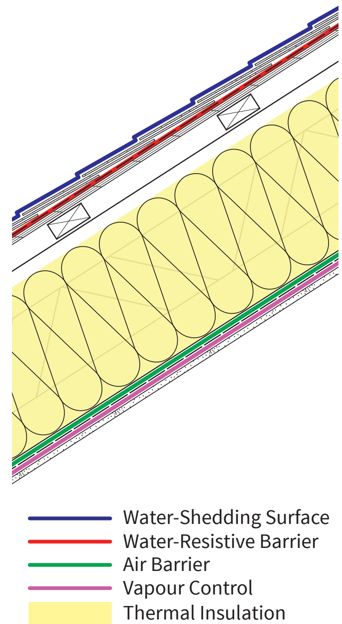
To perform these functions, building assemblies typically use a series of layers, each intended to serve one or multiple functions within the building enclosure. As an example, for a conventional flat roof assembly, the roof membrane is both the primary waterproofing and drainage surface to prevent water ingress. The rigid insulation placed beneath the roofing membrane serves as the thermal insulation to limit heat flow through the assembly. The impermeable adhered membrane placed on the roof sheathing restricts bulk air movement into and out of the building, and controls interior vapour diffusion into the roof assembly. The relative position of these different layers is fundamental to assembly performance, as is the quality of detailing at transitions and penetrations. Roof assemblies, especially flat roofs, are particularly vulnerable to water ingress from rain and snow, as well as durability issues related to moisture accumulation due to air leakage from within the building.

This guide focuses on vaulted and flat (i.e., non-attic) wood frame roof assemblies which can achieve an effective thermal resistance of R-30 (RSI-5.3) or better while meeting the other performance requirements for roof assemblies. These insulative roof assemblies help to reduce the transmission of heat energy through the building enclosure and consequently reduce the heating and cooling loads of the building, and the overall building energy consumption.

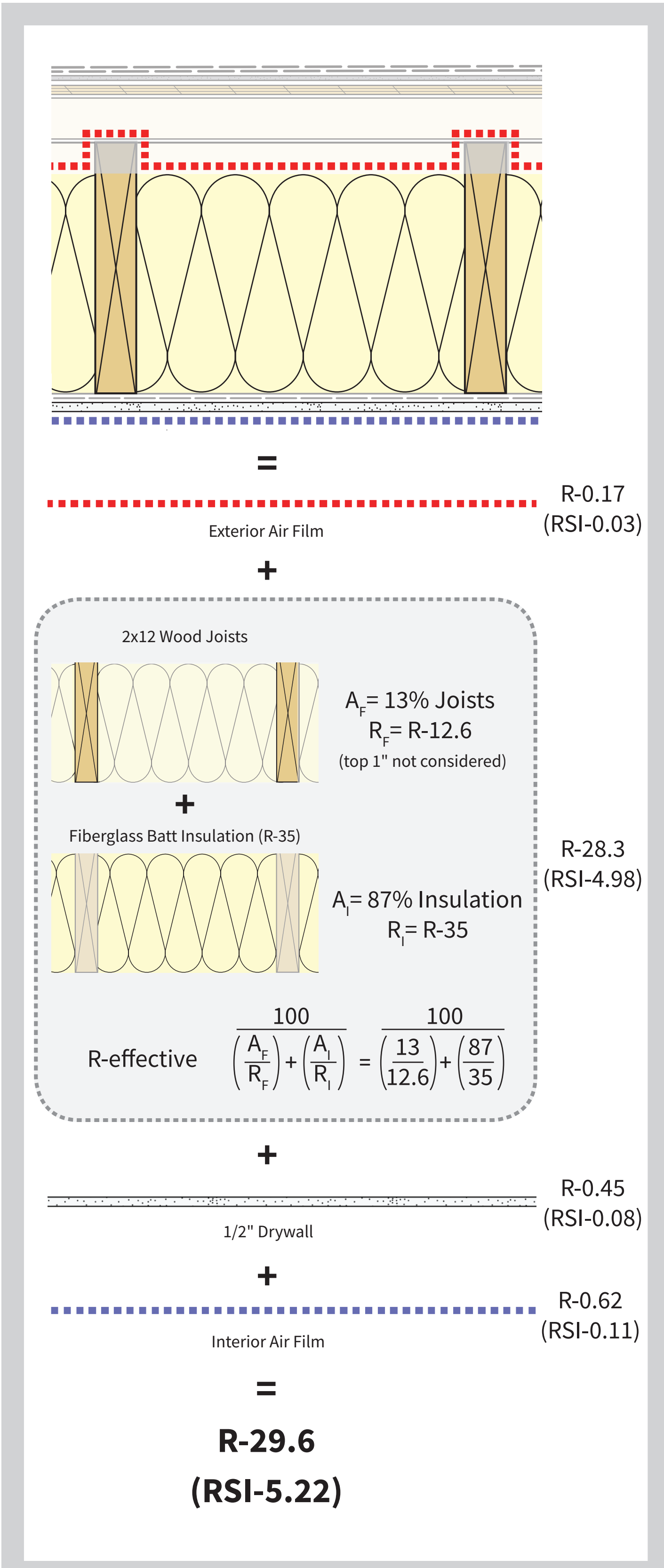
Exposed Membrane
Conventional Flat Roof Assembly



Vaulted Roof Assembly



BC Building Code (BCBC) and Vancouver Building Bylaw (VBBL) Compliance | In many cases this guide indicates best practices with respect to air, vapour, and moisture management, rather than minimum requirements as specified by relevant building regulations. This approach is intended to promote the construction of effective and durable assemblies. Furthermore, in some cases the guide identifies materials, assemblies, or practices for which a registered professional (B.C. architect or engineer) may be required by the Code and/or the authority having jurisdiction to indicate compliance with relevant building regulations. Relevant building regulations should be reviewed and complied with for each project.



R-value Calculations

The thermal resistance of building assemblies is commonly indicated using R-value, provided in imperial units of [$ft^2 \cdot °F \cdot hr/Btu$], and can also be provided as RSI-value, in metric units of [$m^2 \cdot K/W$]. All R-values in this guide are provided in imperial units. The higher the R-value, the better the thermal performance. U-values are another way of describing heat flow through the assembly, and are the inverse of R-values. The lower the U-value, the better the thermal performance.

$$\text{RSI-1 } [m^2 \cdot K/W] = \text{R-5.678 } [ft^2 \cdot °F \cdot hr/Btu]$$

$$R = 1/U$$

For wood frame low-rise residential construction, R-values can be calculated according to Section 9.36 of the British Columbia Building Code (BCBC). This section specifies that assembly R-values are to be calculated using the Isothermal Planes method. The R-value of layers of the roof assemblies which include multiple components, such as insulated joist spaces, should be calculated using the Parallel Paths method (i.e., area weighted U-value calculation). Per Appendix Section A9.36.2.4 of the BCBC, all components above the vented air space in a roof assembly are not accounted for in the thermal calculation. An example roof R-value calculation for a joist-insulated vented roof assembly is shown at left.

Material properties, air film properties, joist framing factors (% of the roof area which is wood joists), and the treatment of thermal bridges for calculating R-values (or RSI-values) are provided in Appendix Section A9.36.2.4 of the BCBC and are the basis for calculations in this guide:

- For 16" spacing, a 13% framing factor is assumed for dimensional lumber and 9% for I-joists and trusses.
- For 24" spacing, a 10% framing factor is assumed for dimensional lumber and 6% for I-joists.
- Thermal bridging by discontinuous penetrations through the insulation (such as fasteners, pipes and ducts, and minor structural members) does not need to be accounted for. Major penetrations such as beams and columns do not need to be included as long as they form less than 2% of the gross area, and the surrounding insulation is installed tight against the penetrating element.

R-value Calculations for Non-Part 9 Buildings

Non-Part 9 projects may include different thermal calculation requirements and ways of accounting for thermal bridging. The specific calculation methods should be referenced depending on the building type, jurisdiction, and energy performance target. The following list outlines the various basic R-value and thermal bridging calculation methodologies of the major code compliance and energy performance pathways in BC:

- Vancouver Part 9 low-rise residential buildings - Refer to BCBC Part 9.36.2.4
- Vancouver 4-6 storey residential buildings (prescriptive pathway) - Refer to BCBC Part 9.36.2.4
- Vancouver 4-6 storey residential buildings (performance pathway) - Refer to Vancouver Energy Modelling Guidelines
- BCBC 2018 Part 3 buildings, ASHRAE 90.1 2016, NECB 2015, BC Energy Step Code - Refer to calculation methods outlined in each standard
- Passive House building - refer to the Passive House certification/design criteria

For more guidance on R-value calculations and accounting for thermal bridging, refer to the various guides listed in Additional Resources on page 29.

Effective R-value of Tapered Insulation

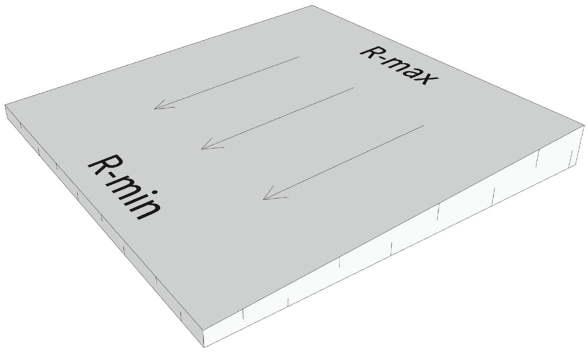
One area where effective insulation values are commonly misunderstood is the use of tapered insulation for flat roofs. There is a non-linear relationship between the taper depth and the R-value, meaning that the average at maximum and minimum R-values does not accurately describe the effective thermal resistance of the insulation. Essentially, the effective R-values are calculated based on integrated area-weighted U-values and cannot be found by taking the value halfway between the minimum R-value (R_{min}) and the maximum R-value (R_{max}) as shown in the table below. The logarithmic formula for effective R-value of rectangular tapered insulation is shown below (see Table A):

$$R_{eff} = \frac{R_{max} - R_{min}}{ln\left[\frac{R_{max}}{R_{min}}\right]}$$

The logarithmic formula for effective R-value of triangular tapered insulation sloped to centre is shown below (see Table B):

$$R_{eff} = \left[\frac{2}{R_{max} - R_{min}}\left[1 + \frac{R_{min}}{R_{max} - R_{min}} ln\left(\frac{R_{max}}{R_{min}}\right)\right]\right]^{-1}$$

R_{min} (RSI)	R_{max} (RSI)	R-effective (RSI)	R-average (RSI)
5 (0.88)	20 (3.52)	**10.8 (1.90)**	~~12.5 (2.20)~~
20 (3.52)	25 (4.40)	**22.4 (3.95)**	~~22.5 (3.96)~~



Sample comparison of average and integrated R-value calculations for rectangular tapered insulation (see next page)

The following R-value tables provide the calculation results for tapered rectangular and triangular insulation. For more guidance on sloped insulation R-values, see the *Guide for Designing Energy Efficient Building Enclosures*, published by BC Housing.

Table A: R-value calculation results for rectangular tapered insulation

R_{min} ↓ / R_{max} →	20	25	30	35	40	45	50	55	60
4	9.9	11.5	12.9	14.3	15.6	16.9	18.2	19.5	20.7
5	10.8	12.4	14.0	15.4	16.8	18.2	19.5	20.9	22.1
10	14.4	16.4	18.2	20.0	21.6	23.3	24.9	26.4	27.9
12	15.7	17.7	19.6	21.5	23.3	25.0	26.6	28.2	29.8
14	16.8	19.0	21.0	22.9	24.8	26.6	28.3	30.0	31.6
16	17.9	20.2	22.3	24.3	26.2	28.0	29.8	31.6	33.3
18	19.0	21.3	23.5	25.6	27.6	29.5	31.3	33.1	34.9
20	20.0	22.4	24.7	26.8	28.9	30.8	32.7	34.6	36.4
25	-	25.0	27.4	29.7	31.9	34.0	36.1	38.0	40.0
30	-	-	30.0	32.4	34.8	37.0	39.2	41.2	43.3
35	-	-	-	35.0	37.4	39.8	42.1	44.2	46.4
40	-	-	-	-	40.0	42.5	44.8	47.1	49.3
45	-	-	-	-	-	45.0	47.5	49.8	52.1
50	-	-	-	-	-	-	50.0	52.5	54.8
55	-	-	-	-	-	-	-	55.0	57.5
60	-	-	-	-	-	-	-	-	60.0

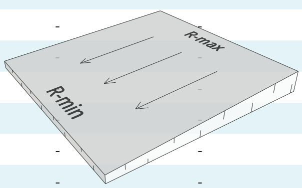
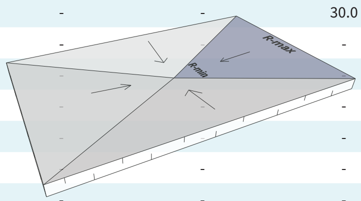


Table B: R-value calculation results for triangular tapered insulation

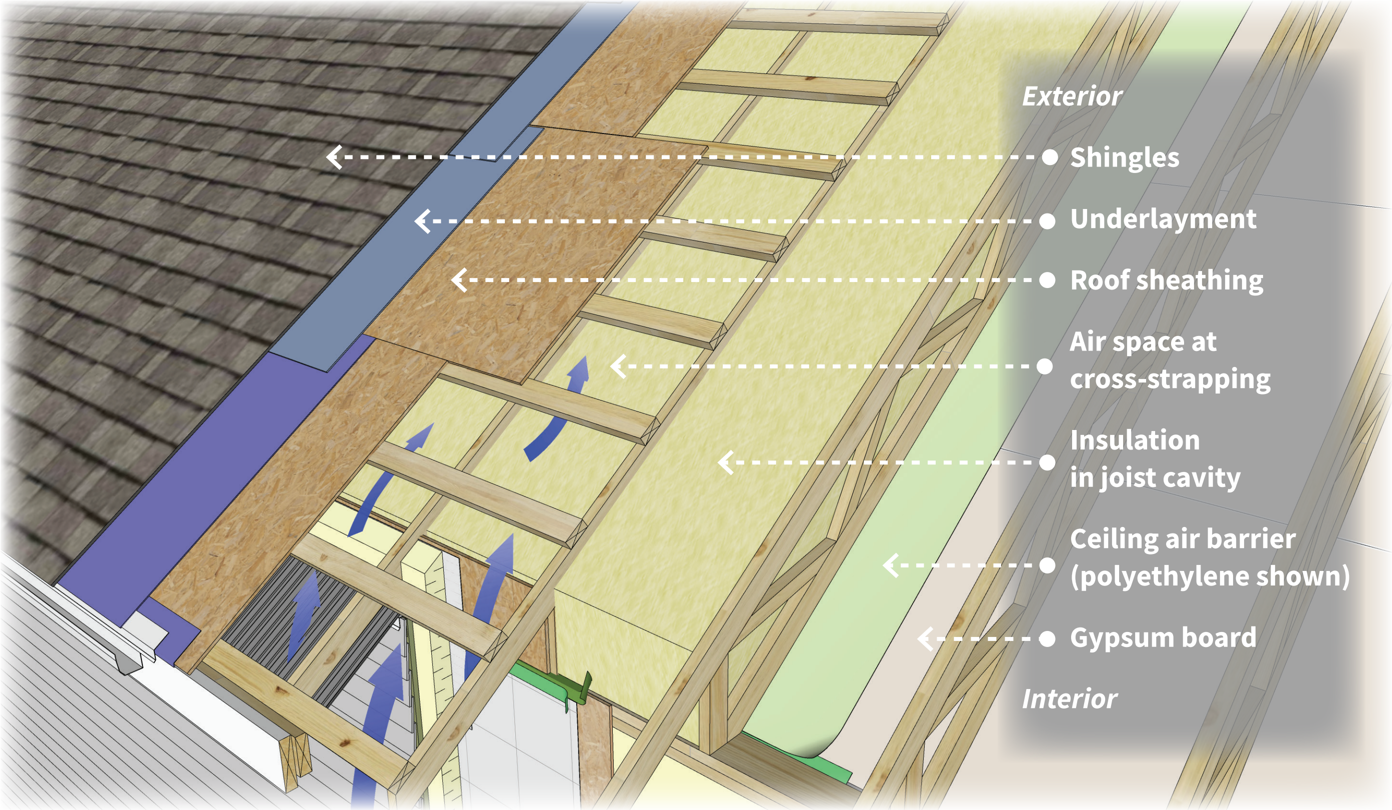
R_{min} ↓ / R_{max} →	20	25	30	35	40	45	50	55	60
4	13.4	16.1	18.8	21.5	24.2	26.8	29.5	32.1	34.7
5	13.9	16.7	19.5	22.2	24.9	27.6	30.2	32.9	35.5
10	16.3	19.3	22.2	25.1	27.9	30.7	33.5	36.2	39.0
12	17.1	20.2	23.1	26.0	28.9	31.8	34.6	37.4	40.2
14	17.9	21.0	24.0	27.0	29.9	32.8	35.6	38.5	41.3
16	18.6	21.8	24.9	27.9	30.8	33.8	36.7	39.5	42.4
18	19.3	22.5	25.7	28.7	31.7	34.7	37.6	40.5	43.4
20	20.0	23.3	26.4	29.5	32.6	35.6	38.5	41.5	44.4
25	-	25.0	28.3	31.5	34.6	37.7	40.7	43.7	46.7
30	-	-	30.0	33.3	36.5	39.7	42.8	45.8	48.9
35	-	-	-	35.0	38.3	41.5	44.7	47.8	50.9
40	-	-	-	-	40.0	43.3	46.5	49.7	52.9
45	-	-	-	-	-	45.0	48.3	51.6	54.8
50	-	-	-	-	-	-	50.0	53.3	56.6
55	-	-	-	-	-	-	-	55.0	58.3
60	-	-	-	-	-	-	-	-	60.0



Sloped insulation effective R-value calculations from the supplier | Some roofing material suppliers offer assistance in designing the sloped roof insulation (also referred to as the taper package), including the calculation of its effective R-value. However, they should confirm that the calculation uses the integrated area-weighted approach rather than the simple average insulation thickness.

Joist-Insulated Vented Vaulted Roof

This vaulted roof assembly consists of insulated roof joists with ventilation beneath the roof sheathing. The depth of the insulation is limited by the depth of the roof joists, with allowance for ventilation. Engineered trusses can be used to create a deep joist space. The joist space can be insulated using a variety of different insulation types including stone wool or fiberglass batt, and, where dedicated vent spaces are created in the full length of the joist using baffles, blown-in fibrous insulation (i.e., cellulose or fiberglass) or spray foam. Clearance between the insulation and the sheathing is provided by purlins (i.e., cross-strapping) at least 1.5" thick, plus 1" in the joist space, for a total of 2.5" ventilation clearance. The cross-strapping perpendicular to the joists provides ventilation pathways across the top of the insulation in all directions. Continuity of the air barrier at the ceiling is critical to the performance of this assembly. A service cavity can be constructed above the ceiling finish to allow for running of services without penetrating the ceiling air barrier.



Key Performance Items

- Venting must be provided at the eaves and the roof ridge, and air must be able to reach all areas beneath the roof sheathing.
- Continuous roof slope is important to allow drainage of water, including melting snow, from all areas. Where possible, long valleys with lower slopes should be avoided.
- **Difficulty in achieving adequate venting, sensitivity to interior air leakage, and an assembly configuration where water can be trapped inside undetected on the polyethylene puts this roof assembly at a risk of long-term performance issues over the service life of the roof. Therefore, its uses must be carefully considered.**

Water Penetration Control

This assembly sheds all exterior water by gravity drainage over shingled materials. The sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water. The underlayment provides a secondary line of protection. Traditionally, asphalt-saturated organic underlayment has been used, but newer synthetic products are becoming more common and may be preferred.

Air Barrier

Both the membrane (i.e., polyethylene) and airtight-drywall approaches can be used for the air barrier. Detailing at intersecting wall assemblies and penetrations, such as plumbing stacks, is important for maintaining the air barrier's continuity and effectiveness. Air barrier continuity is necessary to restrict warm moisture-laden air from depositing moisture within the roof assembly, and to meet the airtightness targets for energy-efficiency.

Insulation & Ventilation

Stone wool, fiberglass batt, blown-in fibrous insulation (i.e., cellulose or fiberglass), or spray foam can be used to insulate the joist space.

Vapour Control

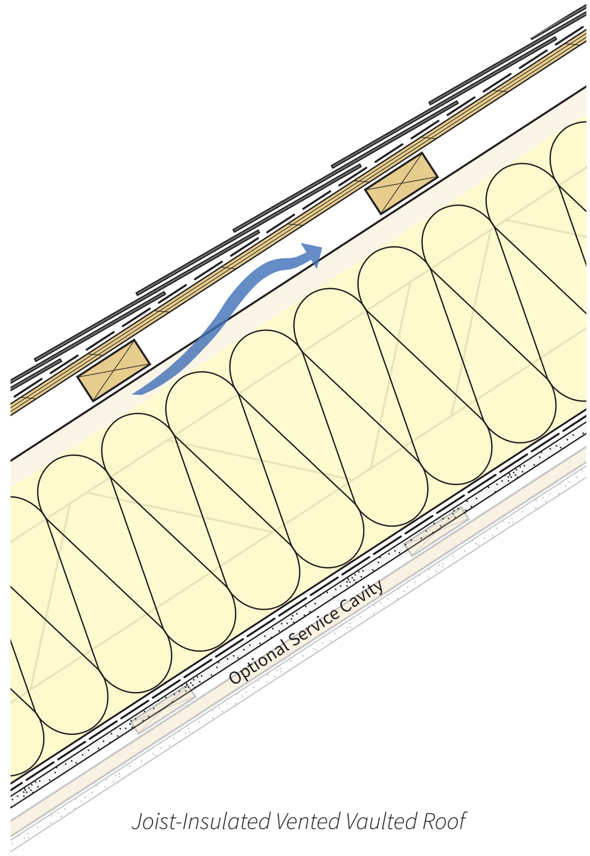
Polyethylene or vapour retarder paint provides the vapour retarder for control of outward vapour diffusion. A smart vapour retarder, which can allow some vapour diffusion inwards, can also be considered in this assembly. Note that proprietary products may require additional code compliance steps.

Design Considerations

In BC coastal climates, vented vaulted roof assemblies may be at risk of surface mould growth on the sheathing as a result of moisture in ventilation air. Sheathing surface treatment to inhibit mould growth may be prudent in these roof assemblies to reduce this risk.

For assemblies with many ceiling penetrations, such as for electrical services, it will be difficult to achieve a continuous interior air barrier. To avoid these penetrations, an interior service cavity beneath the ceiling air barrier can be used to run services. See 6 | Airtightness on page 22 for more guidance on achieving good roof assembly airtightness.

Roof colour plays an important role in the durability of the assembly. Dark grey or black roofs will reach higher temperatures when exposed to direct sunlight, compared to lighter-coloured roofing materials. This can lead to increased thermal stress on the material; however, higher temperatures provide drying benefits that could make the assembly more durable.



Joist-Insulated Vented Vaulted Roof

Effective R-values - Vaulted Roof [ft² •°F•hr/Btu]

2x Framing				
Framing Depth	16" o.c.		24" o.c.	
	R-3.4	R-4.0	R-3.4	R-4.0
2x8 (7¼")	18.5	20.6	20.5	23.0
2x10 (9¼")	24.0	26.7	26.4	29.6
2x12 (11¼")	29.6	32.9	32.3	36.3
I- Joist or Wood Truss Framing				
Framing Depth	16" o.c.		24" o.c.	
	R-3.4	R-4.0	R-3.4	R-4.0
9½"	25.8	29.0	28.3	32.1
11⅞"	32.7	36.7	35.6	40.5
14"	38.8	43.7	42.2	48.0
16"	44.6	50.2	48.3	55.0
20"	56.1	63.2	60.6	69.1
24"	67.7	76.3	72.9	83.2

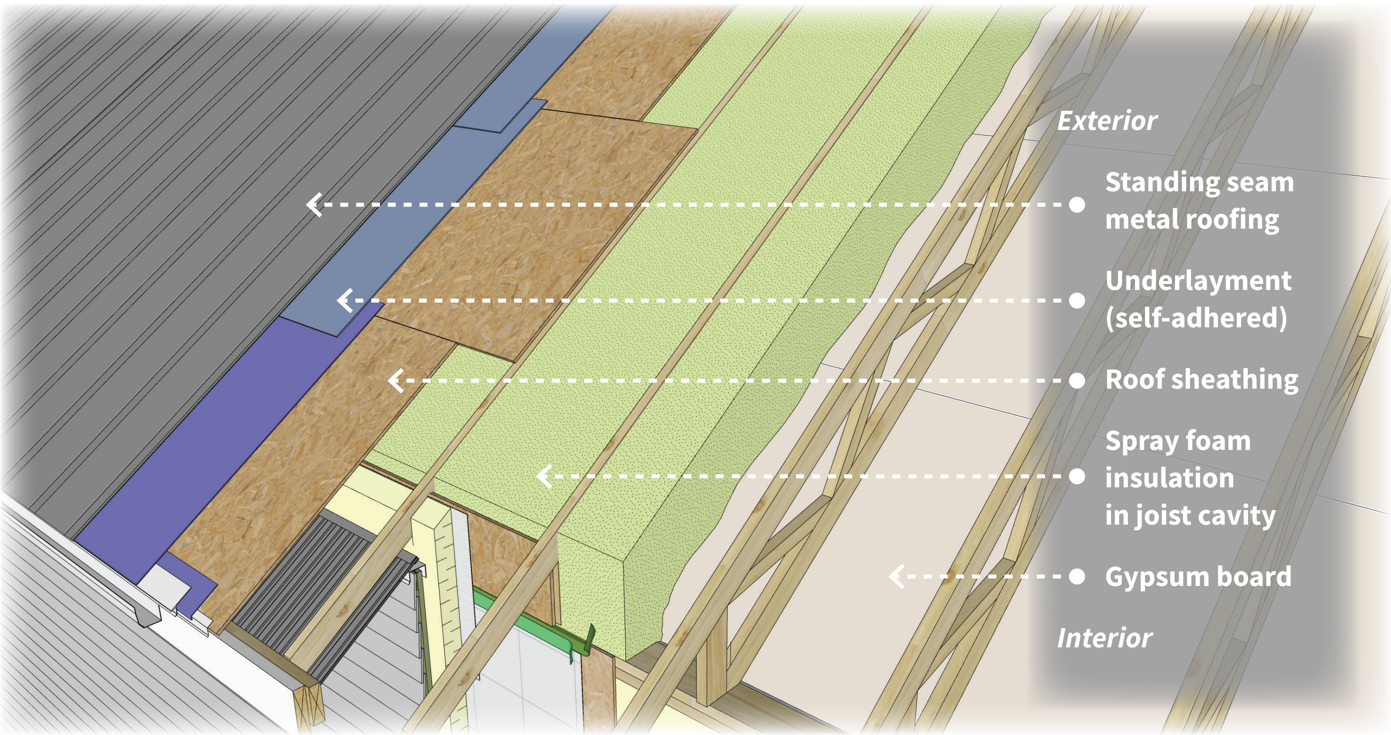
R-values below the R-30 requirement.

All components above vented air space not accounted for.

For assemblies with a 1.5" service cavity, add R-1.0 to the effective R-value.

Joist-Insulated Unvented Spray Foam Vaulted Roof

This vaulted roof assembly consists of spray foam applied to the underside of the roof sheathing between roof joists. The depth of the insulation is limited by the depth of the roof joists, with no allowance for ventilation. The joist space can be insulated using a closed-cell (medium density) spray foam, or open cell (low-density) spray foam. Only spray-applied foam should be used. Careful design and application strategies must be used. Continuity of the air barrier and robust waterproofing details are critical to the performance of the assembly, because the lack of ventilation reduces the drying capacity of this assembly, making it more susceptible to durability issues. Where possible, this assembly should be used with more robust waterproofing components.

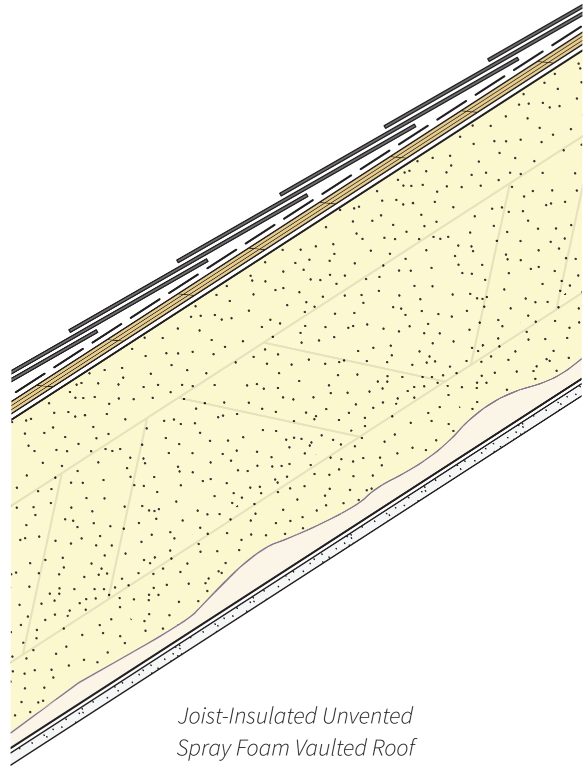


Key Performance Items

- All roof framing and sheathing components must be dry when foam is installed to avoid trapping moisture.
- Standing seam metal roofing is recommended, as some asphalt shingle manufacturers will shorten warranties when shingles are installed above unvented roof assemblies filled with spray foam insulation. See page 25 for an example.
- Besides good roof detailing and watertightness, the performance of the assembly depends on adequate airtightness of the ceiling, which relies on full adhesion of spray foam, and continuity at penetrations and across framing members.
- Sensitivity to interior air leakage, no ventilation strategy, and an assembly configuration where water can be trapped inside undetected puts this roof assembly at risk of long-term performance issues over the service life of the roof.
- Low-density spray foam insulation does not perform as a vapour barrier and must be used with a dedicated vapour retarder.
- This roof type relies on high-quality roof installation and timely maintenance and renewals over its service life.
- **Some jurisdictions require specific professional design and construction oversight for unvented/spray foam roofs. Consult with the local authority having jurisdiction (AHJ) for requirements for design and construction of these assemblies.**

Water Penetration Control

This assembly sheds all exterior water by gravity drainage over shingled materials. The sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water. The underlayment provides a secondary line of protection. Traditionally, asphalt-saturated organic underlayment has been used, but newer synthetic products are becoming more common and may be preferred. Because no ventilation strategy is used, the assembly is sensitive to exterior moisture that penetrates at a roof leak location since its drying capability is limited (see 4 | Spray Foam in Roofs on page 19). Note that the use of an unvented assembly may reduce the roofing product manufacturer's warranty, specifically for roof shingles.



Joist-Insulated Unvented Spray Foam Vaulted Roof

Air Barrier

The foam and framing may be considered the primary element of the air barrier system. Because no ventilation strategy is used, special attention must be paid when applying foam, to ensure the installation of a continuous air barrier.

Insulation

The joist spaces are typically insulated using closed-cell spray foam (~R-6/inch). This material serves as the thermal, air and vapour control layer. If properly applied, the spray foam will adhere well to the roof sheathing and framing. Because the foam is applied to the underside of the sheathing, it is important that the substrate is clean and dry to ensure full adhesion. Poor installation of the spray foam can allow for air and vapour to enter into the roof assembly. This can be problematic in unvented roofs, as they possess low drying capacity. Open-cell spray foam (~R-3.7/inch) can also be used, installed to the full thickness of the joist cavity and trimmed flush, though it's use should be carefully considered. (See 4 | Spray Foam in Roofs on page 19).

Vapour Control

Closed-cell foams provide sufficient resistance to vapour diffusion, controlling the outward movement of interior moisture in most situations. Lighter density open-cell foams must utilize a dedicated vapour retarder membrane at the interior such as polyethylene sheet (see 4 | Spray Foam in Roofs on page 19).

Design Considerations

Roof colour plays an important role in the durability of the assembly. Dark grey or black roofs will reach higher temperatures when exposed to direct sunlight, compared to lighter-coloured roofing materials. This can lead to increased thermal stress on the material; however, higher temperatures provide drying benefits that could make the assembly more durable.

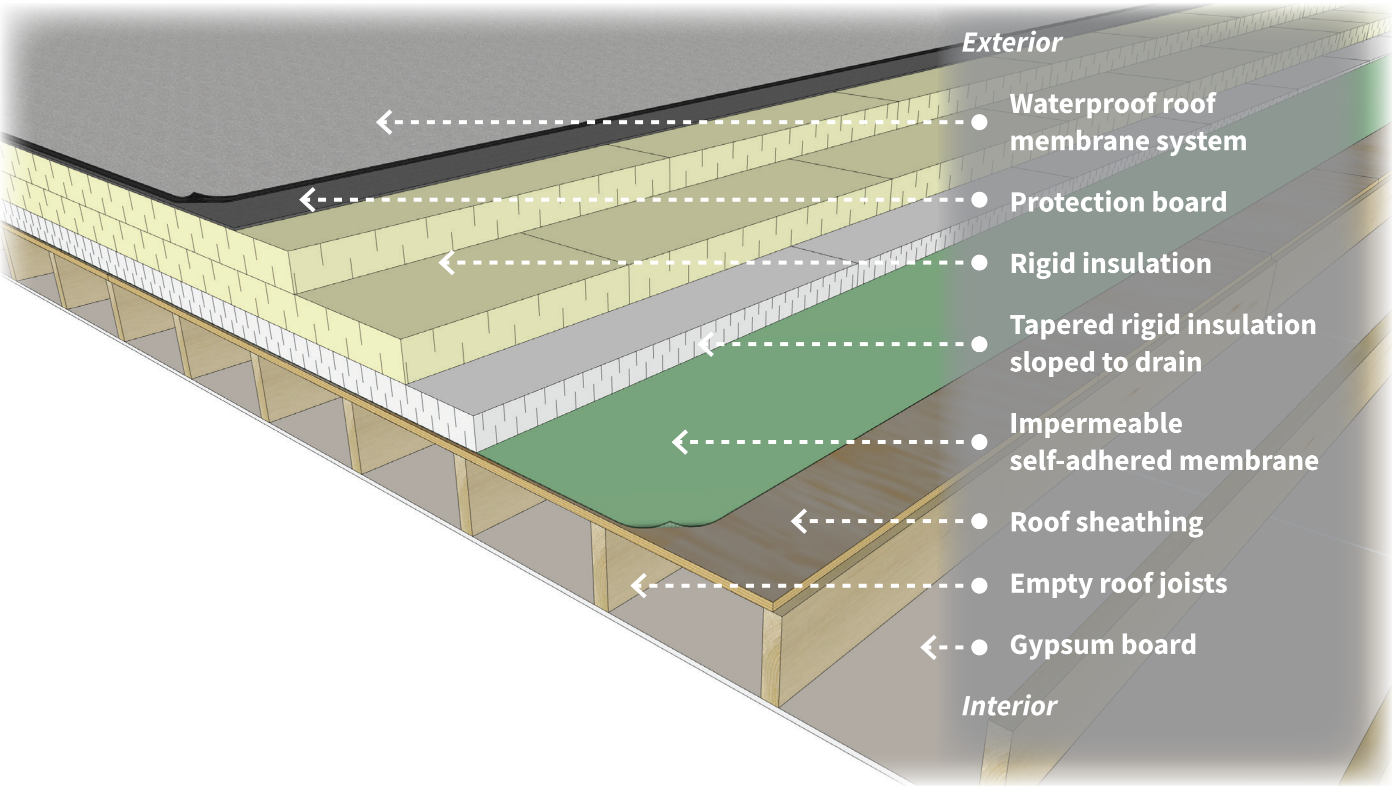
Effective R-values - Vaulted Roof [ft² •°F•hr/Btu]				
2x Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.7	**R-6**	**R-3.7**	**R-6**
7.25"	22.5	24.0	24.0	26.3
9.25"	28.4	32.0	30.2	35.1
11.25"	34.2	39.9	36.5	44.0
I-Joist or Wood Truss Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.7	**R-6**	**R-3.7**	**R-6**
9.5"	30.5	35.4	32.6	39.2
11.875"	37.8	45.6	40.4	50.7
14"	44.4	54.7	47.5	61.0
16"	50.5	63.3	54.1	70.7
20"	62.8	80.6	67.3	90.1
24"	75.1	97.8	80.5	109.5

R-values below the R-30 requirement.

R-6 values (for closed-cell spray foam) assume insulation thickness 1" less than framing depth.

Exposed Membrane Conventional Flat Roof

This flat roof assembly consists of rigid insulation placed on the exterior of uninsulated roof joists. High effective R-values are achieved by using continuous insulation outboard of the sheathing with thermally efficient attachments or adhesive. The waterproof roofing membrane, applied directly to the insulation or over a protection board, controls all exterior moisture. The self-adhered impermeable sheathing membrane over the roof sheathing is used as the air barrier and vapour retarder. Ventilation of this assembly is not necessary. Various types of rigid board insulation can potentially be used in this assembly. This assembly is sloped using the framing components or tapered insulation.



Key Performance Items

- An EPS sloping package installed with the roof insulation as shown is often the simplest way to achieve required sloping.
- Detailing to ensure continuity of the waterproof membrane at the interfaces and penetrations is a significant factor in the overall performance and durability of the assembly.
- Multiple insulation layers should be offset in two horizontal directions to provide a continuous thermal insulation layer. This roof relies on the secure attachment of the rigid insulation for adequate wind uplift resistance of all assembly components. Insulation attachment methods include roofing adhesives and/or mechanical fasteners through the insulation to the roof framing.
- The insulation layers must be protected from damage during construction and roof membrane application. An asphalt protection board or gypsum board layer is recommended above the insulation.

Water Penetration Control

This assembly anticipates the control of all moisture at the waterproof membrane above the insulation. The waterproof membrane surface and drainage surface are coincident. The assembly is sensitive to exterior moisture that penetrates at a roof leak location since water can migrate within the insulation and quickly saturate the roof if undetected. The self-adhered membrane at the sheathing can stop moisture from reaching the sheathing and roof structure, so regular top side inspection is necessary to detect leaks. Wood-frame flat roofs should use robust roofing systems and detailing.

Air Barrier

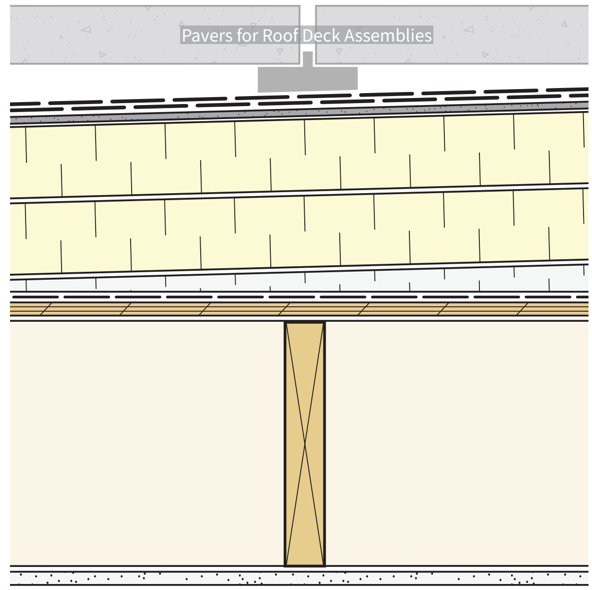
The self-adhered or torch-on membrane (over appropriate protection layer) at the roof sheathing can be considered the primary element of the air barrier system in this assembly. Alternately, roof sheathing could form part of the air barrier system.

Insulation

Various rigid insulation materials such as expanded polystyrene (EPS), polyisocyanurate (polyiso), and rigid stone wool (≥11 lbs/ft^3) can be installed in a conventional roof system. The insulation type used should be chosen with consideration for the expected heat exposure, thermal cycling, and possible loads from foot traffic the roof will experience. Foam insulations have been observed to move and shrink in the assembly. More thermally stable insulation, such as rigid stone wool, may be more appropriate in some applications or as the top insulation layer. Where multiple insulation layers are used, joints in each layer should be offset in two horizontal directions to provide a continuous thermal insulation layer.

Vapour Control

The roof sheathing and self-adhered vapour retarder membrane provide sufficient vapour resistance to control outward vapour flow, and are well located with all moisture sensitive components on the interior side of these layers. Note that rigid insulation is not considered a moisture sensitive material, though some types may become damaged if they are left saturated for long periods of time.



Exposed Membrane Conventional Flat Roof

Effective R-values - Conventional Flat Roof [ft^2 •°F•hr/Btu]		
Nominal R-value of Insulation	**Effective R-value**	**Approx. Insulation Thickness**
R-24	26.9	4" - 6"
R-28	30.9	5" - 7"
R-30	32.9	5.5" - 7.5"
R-35	37.9	6" - 8.5"
R-40	42.9	7" - 10"
R-45	47.9	8" - 11"
R-50	52.9	9" - 12.5"
R-60	62.9	10.5" - 15"

R-values below the R-30 requirement.

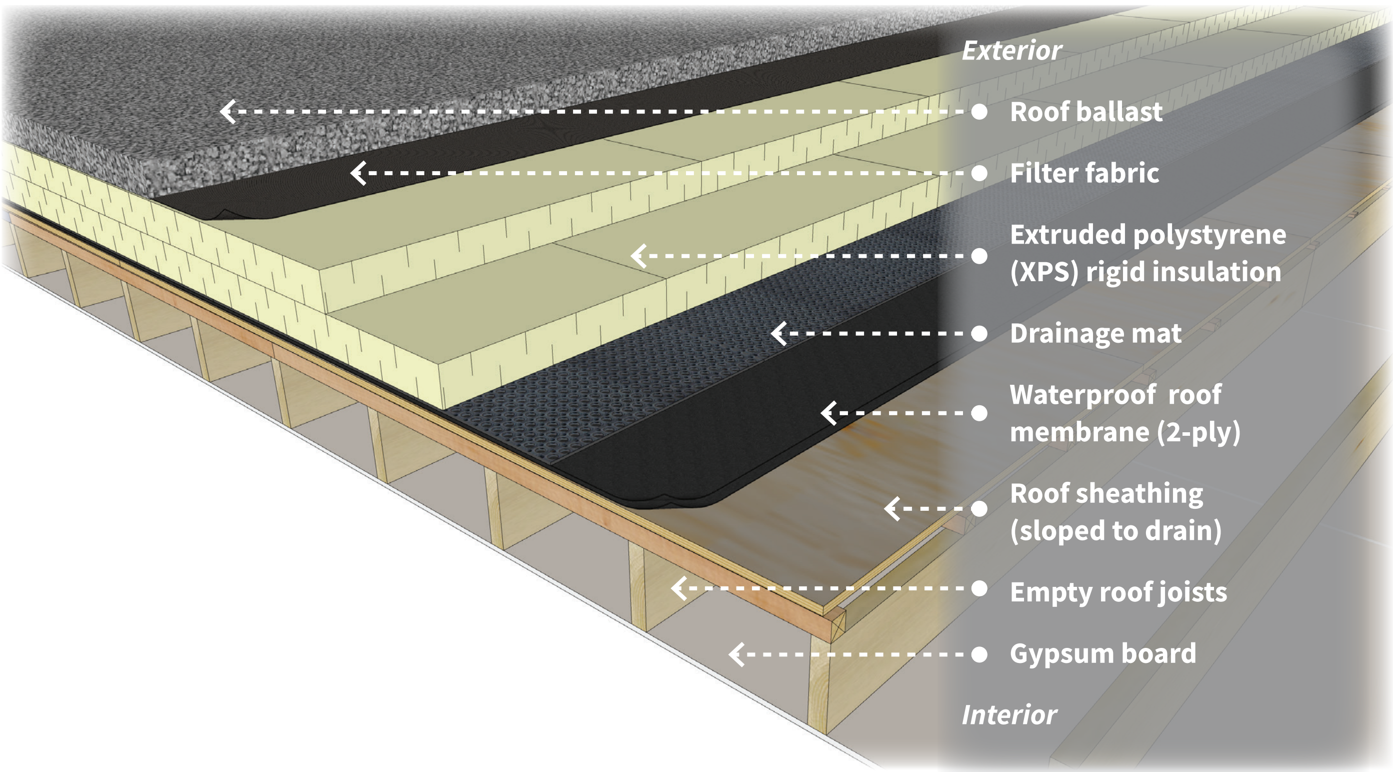
Thermal bridging through the exterior insulation and insulation sloping package is not accounted for.

Design Considerations

An EPS sloping package installed with roof insulation as shown is often the simplest way to achieve required consistent sloping. For roofs that use pavers, the system requires careful selection of paver supports, and must allow access to the roof membrane for inspection and maintenance. Paver pedestals may also create point-loads on roof membranes and cause localized damage to the roof membrane. Therefore, the waterproofing membrane below areas of the roof that may be subject to excessive weight or foot traffic should be reviewed as part of the annual or bi-annual maintenance procedure. The thickness of the exterior insulation above the framing may limit the accessibility for roof decks unless door sills are raised or the roof framing is lowered. See Roof Decks on page 21.

Protected Membrane Flat Roof

This flat roof assembly, called a protected membrane or insulated inverted roof assembly, consists of rigid insulation placed on the exterior of the waterproof roofing membrane and uninsulated roof framing. High effective R-values are achieved by using continuous insulation outside of the structural framing, held in place with the roof ballast or pavers. The waterproof roofing membrane beneath the insulation controls all exterior moisture and is used as the air barrier. The drain mat beneath the insulation provides a pathway for water that reaches the roofing membrane to flow to roof drains. Insulation placed on the exterior of the roof membrane and sheathing often improves the durability of the assembly. The thermal performance of the exterior-insulated inverted roof assembly is good, because there is minimal thermal bridging through the insulation.



Key Performance Items

- The waterproof membrane in this assembly is protected from loading—including thermal cycling, ultraviolet light and pedestrian traffic—and therefore can have a longer service life than membranes placed in more exposed environments. Note that the assembly is difficult to maintain and repair because access to the membrane requires removal of overburden such as ballast and insulation.
- Detailing to ensure continuity and adequate drainage of the waterproof membrane at the interfaces and penetrations is a significant factor in the overall performance and durability of the assembly.
- A drainage mat must be provided on the waterproof roofing membrane to facilitate water flow towards drains.

Water Penetration Control

This assembly controls exterior water at the waterproof roof membrane system, with some water being shed to the drains from the top of the ballast and insulation layers. The waterproof membrane in this assembly is protected from loading—including thermal cycling, ultraviolet radiation and pedestrian traffic—and therefore can have a longer service life than a membrane exposed to the environment. Wood-frame flat roofs should use robust roofing systems and detailing. Two-ply torch-on systems are recommended in most cases. The roofing system should be designed and installed according to the manufacturers' recommendations.

Air Barrier

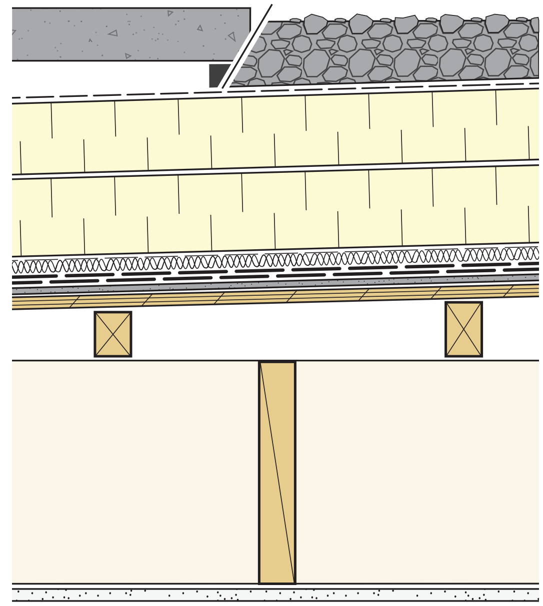
The waterproof roofing membrane is the primary air barrier element in this assembly. It is important that it is installed continuously to reduce the likelihood of air or water bypassing the membrane. It is also more difficult to access the waterproof roof membrane for maintenance once the roof system is fully constructed. Therefore, ensuring continuity during the installation of the membrane is critical.

Insulation

Extruded polystyrene (XPS) is typically installed within an inverted roofing system. Because the waterproof roofing membrane is located below the insulation in this system, the insulation must be able to withstand exposure to water. Where multiple insulation layers are used, each layer should be offset in two horizontal directions to provide a continuous thermal insulation layer.

Vapour Barrier

The waterproof roof membrane system provides sufficient vapour resistance to control outward vapour flow at an ideal location, since moisture present on either side of this membrane has an opportunity to drain or dry.



Protected Membrane Flat Roof

Effective R-values - Conventional Flat Roof [ft² •°F•hr/Btu]

Nominal R-value of Insulation	Effective R-value	Approx. Insulation Thickness
R-24	26.9	4" - 6"
R-28	30.9	5" - 7"
R-30	32.9	5.5" - 7.5"
R-35	37.9	6" - 8.5"
R-40	42.9	7" - 10"
R-45	47.9	8" - 11"
R-50	52.9	9" - 12.5"
R-60	62.9	10.5" - 15"

R-values below the R-30 requirement.
Thermal bridging through the exterior insulation from water flow is not accounted for.

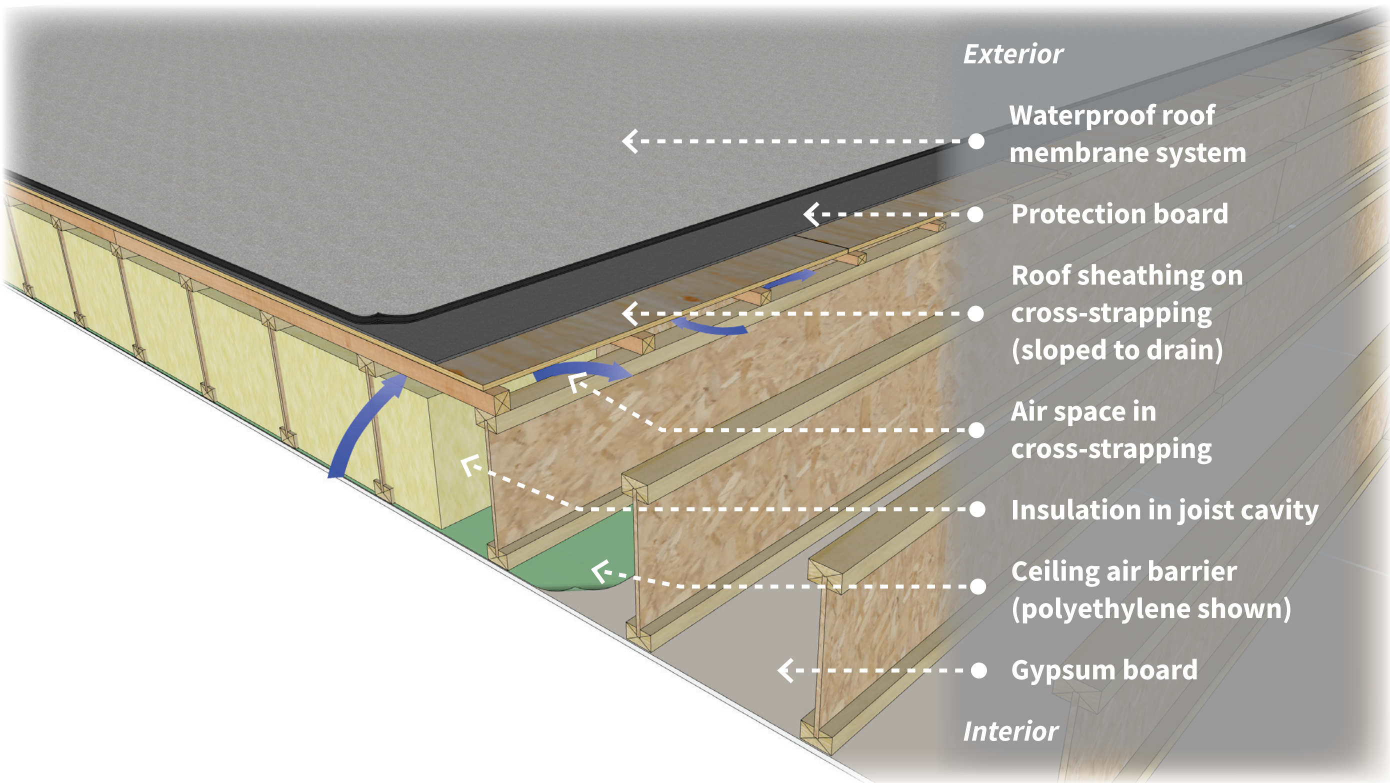
Design Considerations

Unlike a conventional roof assembly with tapered insulation for sloped drainage, the roof structure must be sloped or a sloped package must be installed beneath the roofing membrane. Detailing and positive drainage are important for successful performance of this assembly. Water that cannot freely drain from the assembly poses a greater risk to the integrity of the roof membrane, as it will likely remain in contact with the roof membrane for long periods of time.

Effective R-values to account for water flowing between insulation and waterproof roof membrane | Water traveling below the rigid insulation will absorb some heat from the building, which is lost when the water runs to the roof drain. The European standard EN ISO 6946/A1, section D.4.3. accounts for this extra loss with a correction to the U-value of the roof assembly. Providing a water drainage separation layer above the rigid insulation will reduce rainwater penetration and increase the thermal performance of your roof assembly, as this issue cannot be mitigated by adding extra insulation. Accounting for this energy loss is typically not required to demonstrate code compliance.

Joist-Insulated Vented Flat Roof

This flat roof assembly consists of insulated roof joists with ventilation beneath the roof sheathing. The depth of the insulation is limited by the depth of the roof joists, with allowance for ventilation at the joists. Engineered trusses can be used to create a deep joist space. The joist space can be insulated using a variety of different insulation types. Clearance between the insulation and the sheathing is provided by purlins (i.e., cross-strapping) at least 1.5" thick, plus 1" in the joist space, for a total of 2.5" ventilation clearance. Continuity of the air barrier at the ceiling is critical to the performance of the assembly. A service cavity is recommended above the ceiling finish to allow for running of services without penetrating the ceiling air barrier.



Key Performance Items

- Draining the roof is fundamental to its durable performance. Therefore, the location and sizing of drains, and the positive slope to the drains, are critical design features.
- A service cavity at the ceiling will reduce the number of penetrations in the ceiling air barrier and improve its airtightness.
- **Sensitivity to venting and potential interior air leakage, and an assembly configuration that can trap moisture undetected puts this roof assembly at a risk of long-term performance issues over the service life of the roof. Therefore, its uses must be carefully considered.**

Water Penetration Control

This assembly controls all liquid water at the waterproof membrane above the sheathing. The waterproof membrane and drainage surface are coincident. Water must drain over the membrane to centrally located drains or perimeter scuppers. The venting capability of this assembly may help to dry the assembly in the event of a minor leak. Wood-frame low-slope roofs should use robust roofing systems and detailing. Two-ply torch on systems are recommended in most cases.

Air Barrier

Sealed-polyethylene, airtight-drywall or other sealed interior ceiling approaches (see page 22) can be used as air barrier strategies in this assembly. Detailing at intersecting wall assemblies and penetrations are important factors in air barrier effectiveness. Air leakage at the ceiling and resulting condensation can be a problem with these assemblies. As a possible solution, a secondary roof service space could be included at the underside of the roof polyethylene air barrier in order to accommodate ceiling penetrations such as pot lights, without penetrating the air barrier.

Insulation & Ventilation

Stone wool, fiberglass batt, blown-in fibrous insulation (i.e., cellulose or fiberglass), or spray foam can be used to insulate the joist space.

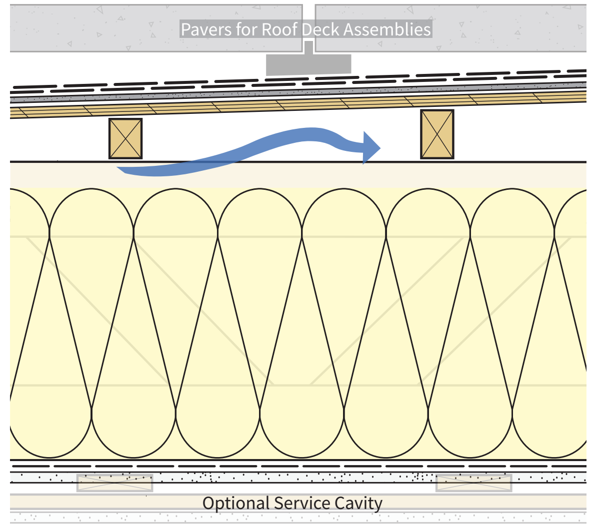
Vapour Control

Polyethylene , vapour retarder paint, or a smart vapour retarder can provide control of outward vapour flow. Difficulty in achieving adequate venting, sensitivity to interior air leakage, and an assembly configuration where water can be trapped inside undetected puts this roof assembly at a higher risk of long-term performance issues over the service life of the roof. Therefore, its use must be carefully considered. Assemblies with all the control layers and insulation on the exterior of the sheathing may be more appropriate as flat roofs.

Design Considerations

In BC coastal climates, vented roof assemblies may be at an elevated risk of surface mould growth on the sheathing as a result of moisture in ventilation air. Sheathing surface treatment to inhibit mould growth may be prudent in these roof assemblies to reduce this risk.

Roof colour also plays an important role in the durability of the assembly. Dark grey or black roofs will reach higher temperatures when exposed to direct sunlight, compared to lighter-coloured roofing materials. This can lead to increased thermal stress on the material; however, higher temperatures provide drying benefits that could make the assembly more durable.



Joist-Insulated Vented Flat Roof

Effective R-values - Vented Flat Roof [ft² •°F•hr/Btu]				
2x Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.4	**R-4.0**	**R-3.4**	**R-4.0**
2x8 (7¼")	18.5	20.6	20.5	23.0
2x10 (9¼")	24.0	26.7	26.4	29.6
2x12 (11¼")	29.6	32.9	32.3	36.3
I- Joist or Wood Truss Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.4	**R-4.0**	**R-3.4**	**R-4.0**
9½"	25.8	29.0	28.3	32.1
11⅞"	32.7	36.7	35.6	40.5
14"	38.8	43.7	42.2	48.0
16"	44.6	50.2	48.3	55.0
20"	56.1	63.2	60.6	69.1
24"	67.7	76.3	72.9	83.2

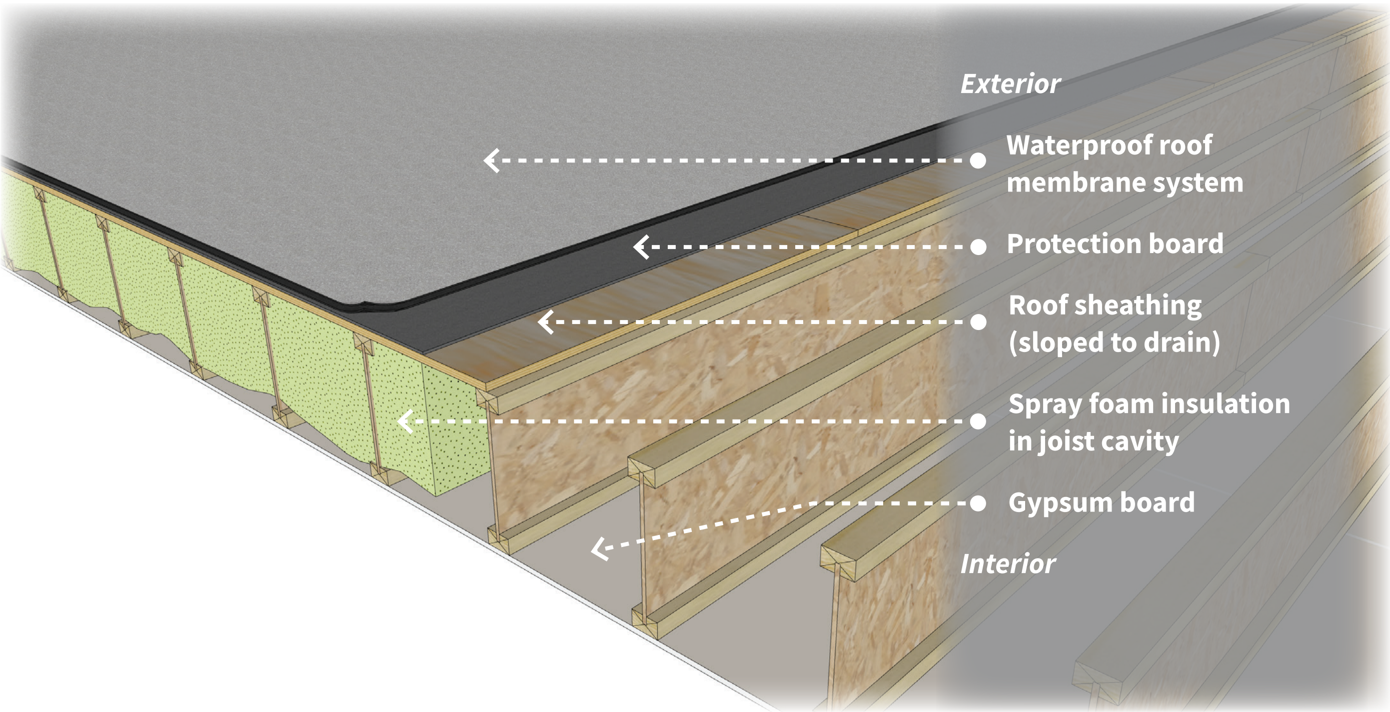
R-values below the R-30 requirement.

All components above vented air space not accounted for.

For assemblies with a 1.5" service cavity, add R-1.0 to the effective R-value.

Joist-Insulated Unvented Spray Foam Flat Roof

This flat roof assembly consists of fully insulated roof joists between the ceiling and the roof sheathing. The depth of the insulation is limited by the depth of the roof joists, with no allowance for ventilation. The joist space can be insulated using a closed-cell (medium density) spray foam or open-cell (low-density) spray foam. Careful design and application strategies must be used. Continuity of the air barrier and robust waterproofing details are critical to the performance of the assembly. The lack of ventilation in this assembly reduces its drying capacity, making it more susceptible to durability issues as a result of localized wetting at roof defects.

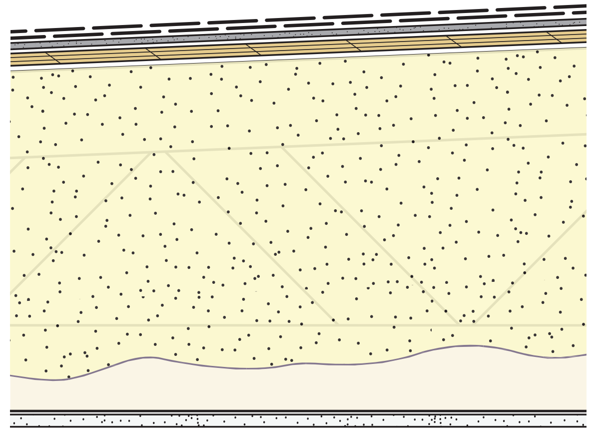


Key Performance Items

- The roof sheathing substrate must be dry when the foam is installed, to avoid any trapped moisture.
- Low-density spray foam insulation does not perform as a vapour barrier and must be used with a dedicated vapour retarder.
- Detailing to ensure continuity of the waterproof membrane at the interfaces and penetrations is a significant factor in the overall performance and durability of the assembly.
- Besides good roof detailing and watertightness, the performance of the assembly depends on adequate airtightness of the ceiling, which relies on full adhesion of the spray foam to the roof sheathing substrate.
- Use of an unvented roof assembly may void the warranty on a membrane installation. Consult with a roofing contractor for more information.
- This roof type relies on high-quality roof installation and timely maintenance and renewals over its service life. Pavers and similar pedestrian surfaces should be removed at least once a year to inspect the roof membrane.
- **Some jurisdictions require specific professional design and construction oversight for unvented/spray foam roofs, restrict the roof membrane to be used and focus on roof details. While all roof assemblies require careful consideration in design and construction, consult with the local AHJ for any special requirements for flat unvented spray foam roofs.**

Water Penetration Control

This assembly controls all liquid water at the waterproof membrane above the sheathing. The waterproof membrane and drainage surface are coincident. Water must drain over the membrane to centrally located drains or perimeter scuppers. The assembly is very sensitive to exterior moisture that penetrates at a roof leak location since water can be trapped by the insulation and saturate the roof framing prior to being detected. Wood-frame flat roofs should use robust roofing systems and detailing. Two-ply torch-on systems are recommended in most cases. The roofing system should be designed and installed according to the manufacturers' recommendations.



Joist-Insulated Unvented Flat Roof

Air Barrier

The foam and framing or the roof sheathing may be considered the primary element of the air barrier system. Because no ventilation strategy is used, special attention must be paid when applying foam in order to ensure the installation of a continuous air barrier.

Insulation

The joist spaces are typically insulated using closed-cell spray foam (~R-6/inch). This serves as thermal, air, and moisture control for this assembly. It must therefore be applied with care. Because the foam is applied to the underside of the sheathing, it is important that the substrate be clean and dry to ensure full adhesion. Poor installation of the spray foam can allow air and vapour to enter the roof assembly. This can be problematic in an unvented, roof as it possesses poor drying capacity. Open-cell spray foam (~R-3.7/inch) can also be installed to the full thickness of the joist cavity and trimmed flush. See 4 | Spray Foam in Roofs on page 19 for more guidance on the use of unvented spray foam roofs.

Vapour Control

Closed-cell foams provide sufficient resistance to vapour diffusion, controlling the outward movement of interior moisture in most situations. Lighter density open-cell foams must utilize a dedicated vapour retarder membrane at the interior such as polyethylene sheet or smart vapour retarder (see 4 | Spray Foam in Roofs on page 19).

Effective R-values - Unvented Flat Roof [ft² •°F•hr/Btu]				
2x Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.7	**R-6**	**R-3.7**	**R-6**
2x8 (7¼")	22.5	24.0	24.0	26.3
2x10 (9¼")	28.4	32.0	30.2	35.1
2x12 (11¼")	34.2	39.9	36.5	44.0
I-Joist or Wood Truss Framing				
Framing Depth	**16" o.c.**		**24" o.c.**	
	R-3.7	**R-6**	**R-3.7**	**R-6**
9½"	30.5	35.4	32.6	39.2
11⅞"	37.8	45.6	40.4	50.7
14"	44.4	54.7	47.5	61.0
16"	50.5	63.3	54.1	70.7
20"	62.8	80.6	67.3	90.1
24"	75.1	97.8	80.5	109.5

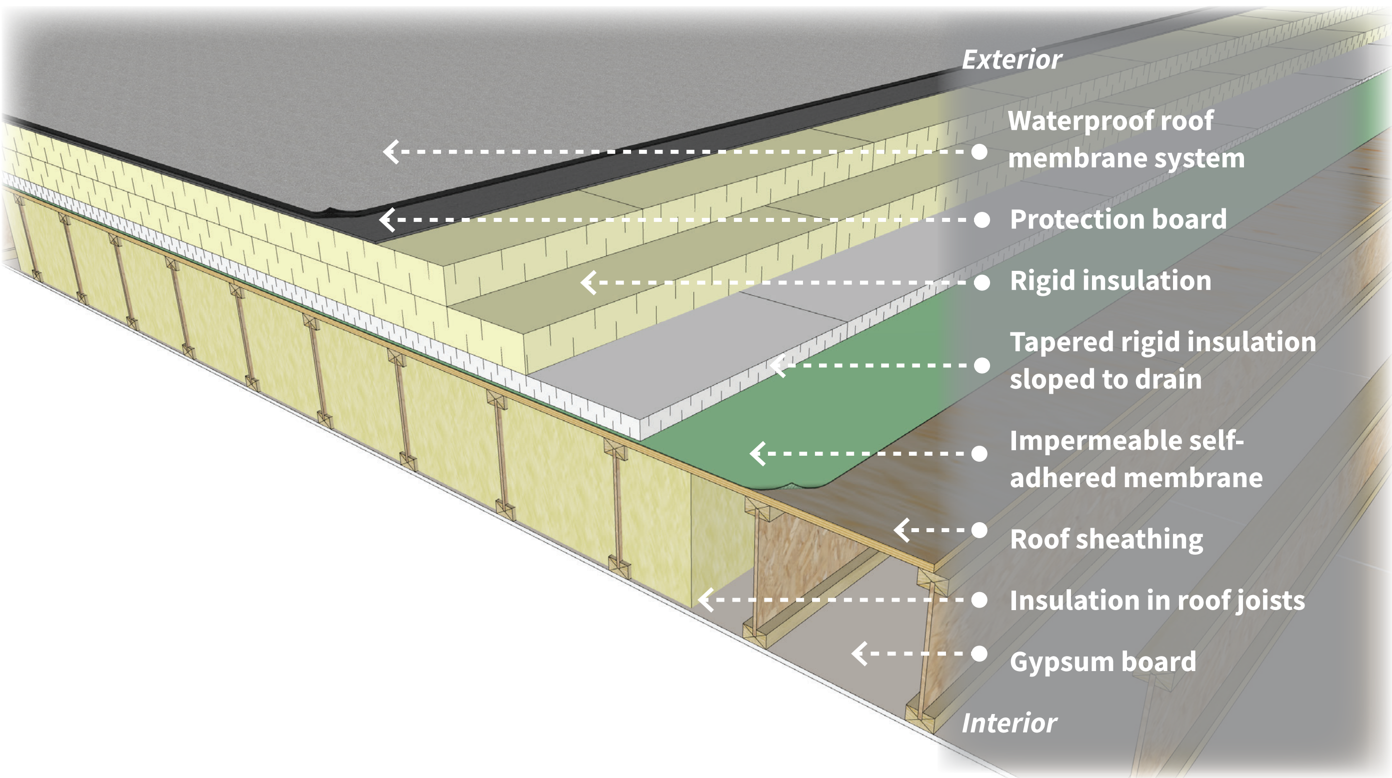
R-values below the R-30 requirement.

R-6 values (for closed-cell spray foam) assume insulation thickness 1" less than framing depth.

Effect of tapered insulation in joist cavity (if applicable) not accounted for.

Split-Insulated Exposed Membrane Flat Roof

This flat roof assembly consists of rigid insulation placed on the exterior of insulated roof joists. High effective R-values are achieved by using continuous insulation outboard of the sheathing with thermally efficient attachments. The depth of the interior insulation is limited by the depth of the roof joists, but could be installed in shallower thicknesses. To reduce the risk of condensation and possible moisture build-up in the roof, the nominal R-value ratio of exterior insulation to interior insulation should be at least two-thirds of the R-value placed on the outside of the roof sheathing, with at most one-third placed inside the joist space. If this ratio cannot be achieved, then a detailed hygrothermal analysis should be completed for the specific roof assembly to assess the risk of condensation and moisture accumulation.



Key Performance Items

- Detailing to ensure continuity of the waterproof membrane at the interfaces and penetrations is a significant factor in the overall performance and durability of the assembly.
- To reduce the risk of condensation and possible moisture build-up in the roof, the nominal R-value ratio of exterior insulation to interior insulation should be at least two-thirds placed on the outside of the roof sheathing, one-third placed inside the joist space, unless specific hygrothermal modelling is done to assess the safety of an alternate ratio.
- Draining the roof is fundamental to its durable performance. Therefore, the location and sizing of drains, and a positive slope to the drains, are critical design features.
- The insulation layers must be protected from damage during construction and roof membrane application. An asphalt protection board or gypsum board layer is recommended above the insulation.

Water Penetration Control

This assembly controls all liquid water at the waterproof membrane above the insulation. The waterproof membrane and drainage surface are coincident. Water must drain over the membrane to drains or perimeter scuppers. The assembly is sensitive to exterior moisture that penetrates at a roof leak location since water can migrate within the insulation and quickly saturate the roof if undetected. The self-adhered membrane at the sheathing can stop moisture from reaching the sheathing and roof structure and interior, so regular inspection from the top side of the roof is necessary to detect leaks. Wood-frame low-slope roofs should use robust roofing systems and detailing.

Air Barrier

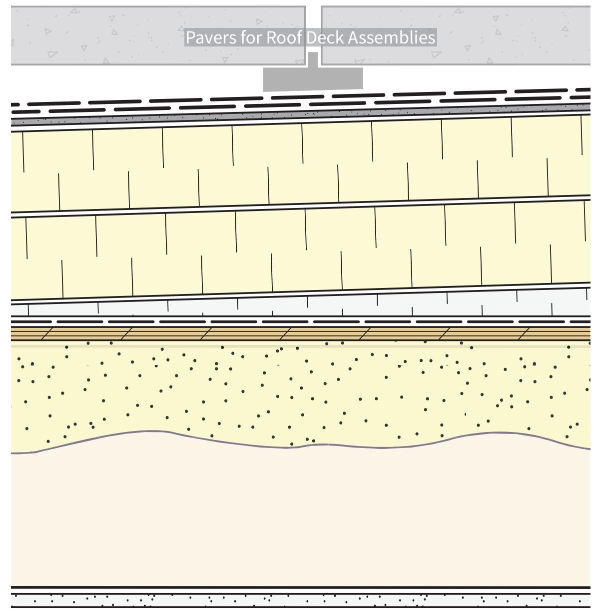
The self-adhered membrane at the roof sheathing can be considered the primary element of the air barrier in this assembly. Alternately, the roof sheathing could form part of the air barrier system.

Insulation

Various rigid insulation materials can be used for the continuous insulation above the sheathing, such as extruded polystyrene (XPS), EPS, polyiosocyanurate (polyiso), and rigid stone wool. The insulation type used should be chosen with consideration for the expected heat exposure and thermal cycling for the roof. An EPS sloping package installed with the roof insulation as shown is often the simplest way to achieve the required sloping. Insulation types installed within the joist cavities can include batt (i.e., stone wool or fiberglass), blown-in fibrous insulation (i.e., cellulose), or spray foam.

Vapour Control

The vapour retarder is the self-adhered membrane on the roof sheathing. The split-ratio of insulation should be 2:1 to include at least 2/3 of the nominal R-value on the exterior side, and the remaining 1/3 of the insulation between the roof joists. In this case, the exterior insulation will keep the roof structure and vapour retarder warm and reduce the risk of condensation at the underside of the sheathing. If this method is not possible, then a detailed hygrothermal analysis should be completed for the specific roof assembly to assess the risk of condensation.



Split-Insulated Exposed Membrane Flat Roof

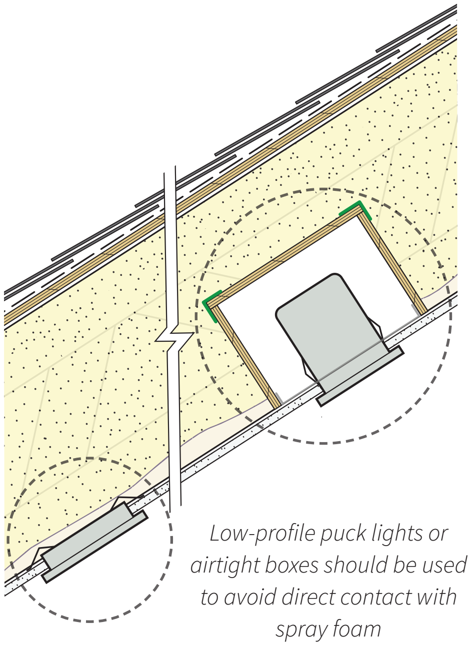
Effective R-values - Split Insulated Flat Roof [ft² •°F•hr/Btu]		
Continuous Exterior Insulation R-value	Interior Insulation Nominal R-value	Assembly Effective R-value
R-24	R-12	**R-35.4**
R-28	R-14	**R-41.0**
R-32	R-16	**R-46.5**
R-40	R-20	**R-57.6**
R-48	R-24	**R-68.7**
R-56	R-28	**R-78.9**
R-64	R-32	**R-90.0**

Table assumes R-4/inch cavity insulation in 7.25" deep dimensional lumber joists at 16" o.c. (9.25" deep for R-32 nominal)

Design Considerations

An EPS sloping package installed with roof insulation as shown is often the simplest way to achieve required consistent sloping. For roofs that use pavers, the system requires careful selection of paver supports, and must allow access to the roof membrane for inspection and maintenance. The thickness of the exterior insulation above the framing may limit accessibility at the roof deck unless the door sills are raised or the roof framing is lowered. See Roof Decks on page 21 .

Application of Spray Foam Roofs



Low-profile puck lights or airtight boxes should be used to avoid direct contact with spray foam

Unvented open-cell and closed-cell spray foam roof assemblies are becoming more common in British Columbia. Closed-cell spray foam offers a higher R-value per inch compared to other standard insulation types. Additionally, by completely filling the joist cavity with spray foam and eliminating the vent space, the full depth of the joists can be used to more easily meet code R-value requirements. The foam is also generally used as the primary air barrier and, for closed-cell spray foam, the vapour retarder. While this approach has been used successfully in many roof assemblies across British Columbia, there is an increased risk associated with the use of unvented spray foam assemblies that may not be present with vented or exterior-insulated assemblies. The following items outline the most important design and construction considerations for unvented spray foam roofs. Note that many of these concepts may also apply to common vented roofs, though to a lesser extent. Also, see Additional R30+ Roofs on page 25 for more examples of fully insulated roof assemblies with alternative ventilation strategies.

Air Barrier & Vapour Retarder Installation

Limiting interior air and vapour movement into the unvented spray foam roof is important to achieving a safe and durable roof assembly. Warm moist interior air that reaches the exterior roof sheathing can condense and cause moisture accumulation at the underside of the sheathing behind the spray foam. If left unchecked, this can lead to long-term damage of both the sheathing and framing members, because the closed-cell spray foam applied directly to the sheathing will limit drying of the wood materials.

Closed-cell spray foam is usually relied upon to provide the air barrier and vapour control layers in the field of the roof assembly. Correctly applied closed-cell spray foam should be continuous across the ceiling plane, with good adhesion to the roof framing members and sheathing. Open-cell spray foams must be combined with a dedicated vapour retarder (i.e., polyethylene or a smart vapour retarder), since the foam itself is vapour permeable. Always use a licensed spray foam applicator for all spray foam installations. Note that additional sealing will likely be needed to achieve good airtightness for an assembly using spray foam as the primary air barrier. Wood members that do not have spray foam on all sides, like double-joists or blocking, must be sealed between all joints in the framing. Penetrations like plumbing stacks and pot lights must be carefully air-sealed. Other air barrier approaches may be more appropriate if high-performance airtightness is intended. Because spray foam is more susceptible to high temperatures, a 3" clearance from heat emitting devices (i.e., pot lights) is required by both ULC S705 & S712. Airtight boxes or low-profile puck lights should be used instead (see above graphic).

Watertightness & Leakage Risks

Unvented roof assemblies risk trapping moisture inside the joist space between the sheathing and the ceiling, since there is little to no means of drying. Spray foam roofs are especially watertight, so that even large accumulations of water can remain undetected for long periods. Consequently, water penetration from the outside at roofing defects presents a large risk for these roof assemblies. As with all roof assemblies, long-term durability requires careful attention to the watertightness of roofing materials. This includes the correct use of flashings, gutters, and drains, as well as regular review and maintenance throughout the service life of the assembly.

Maintenance & Inspections

Early stages of moisture accumulation and damage that may be present in unvented spray foam roofs are likely not detectable visually from the interior, without the use of exploratory openings at the ceiling. Exterior review is the only way to detect potential issues, using visual inspection or thermal imaging to check if the roof sheathing is wet. Roof replacement should be planned for as soon as the lifespan of the roofing system is reached. Note that maintenance and replacement work on spray foam roofs can be difficult and costly.

Open-Cell vs. Closed-Cell Spray Foam

- Closed-cell spray foam has a higher R-value per inch compared to open-cell (~R-6 vs. ~R-3.7 per inch).
- Open-cell spray foam is vapour permeable, whereas closed-cell is impermeable and can be considered as a vapour control layer.
- Though it varies by manufacturer, closed-cell spray foam typically must be applied in maximum 2" lifts and not more than two lifts per 24-hour period. There is no limit to the amount of open-cell spray foam that can be applied in one lift.
- Open-cell spray foam should be installed to the full depth of the framing and cut flush to avoid creating an air space between the interior vapour control layer and the spray foam.
- Closed-cell spray foam can only be installed into open cavities. Unlike open-cell, it cannot be used to fill void spaces behind framing.
- Open-cell spray foam is not listed in the VBBL or BCBC as a spray foam insulation type; however, it is covered in ULC S712.1 & S712.2. Always check with your local AHJ before using open-cell spray foam.

Code Requirements for Spray Foam Roofs

In addition to the guidance provided in this document, the British Columbia Building Code (BCBC) has specific requirements for unvented roofs and spray foam in Part 9 construction. Different jurisdictions may also have additional steps for code compliance; therefore, site-specific regulations must be considered when using spray foam in roofs assemblies.

Requirements for Roofing Ventilation Strategies: BCBC - Article 9.19.1.1 & A-9.19.1.1 (1)

While the code does not give prescriptive guidance on which roof assemblies require ventilation, this language is intended to allow the designer to consider whether an assembly is sufficiently water, air, and vapour tight to minimize the need for ventilation. As discussed in the previous pages, this includes both interior ceiling airtightness and permeance, as well as exterior watertightness and durability. Important points from this specific BCBC Article and Appendix are as follows:

- Unless proven to be unnecessary, a space must be provided between the insulation and the underside of the sheathing, and vents are to be installed to permit the transfer of interior moisture to the exterior.
- The BCBC recognizes that ventilation may not be required as some roof assemblies have, over time, demonstrated that their construction is sufficiently tight, preventing excessive moisture accumulation. Practically, this typically requires that a professional be retained to oversee design and construction of these systems.

Requirements for Spray Foam Installation & Materials: BCBC - Article 9.25.2.5 & 5.3.1.3-3

Foam must be installed by a licensed spray foam installer in accordance with applicable ULC standards. These standards include requirements for:

- framing and sheathing humidity levels,
- testing for proper adhesion of foam to substrates,
- quality of installation to ensure airtightness,
- elimination of air pockets within the foam,
- and more.

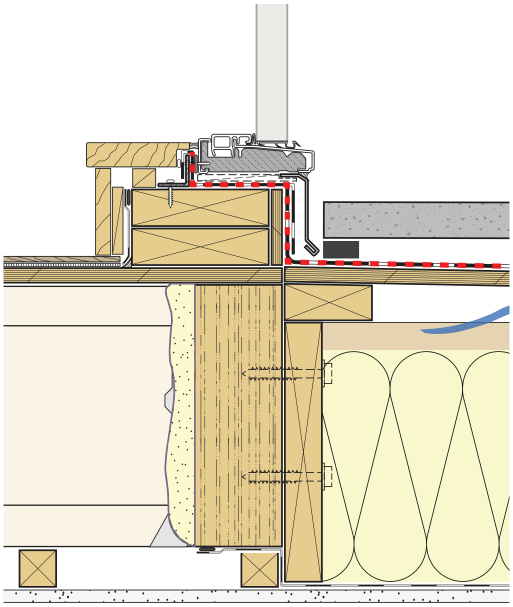
The code includes prescriptive requirements for the installation and material standards that must be used for closed-cell spray foam. As previously noted, open-cell spray foam is currently not included in the code as "spray-in-place polyurethane insulation" and should be considered as a separate product.

Roof Decks

All flat roof assembly types can be used for roofs that allow regular access and foot traffic (i.e., as roof decks). They require careful design and coordination to ensure the performance of the roof assembly and good usability.

Door Sill Height - Structural Coordination

A good design approach is to provide as large a step as possible between the door sill and the surface of the roof deck. The higher the door sill above the drainage surface, the lower the potential for water ingress as a result of snow melt or water back-up. Any portion of the curb or framing within 8 inches of the horizontal roof deck waterproofing must be made waterproof with roofing-grade materials. This could include a torch-applied roofing membrane or a liquid-applied roofing membrane installed from the deck surface up onto the door sill. The roof deck surface must be aligned to allow for both the door sill step and sloping away from the door. This may require the roof deck framing be dropped lower than the adjacent floor framing. Accessibility requirements must also be considered in the design of door sills.



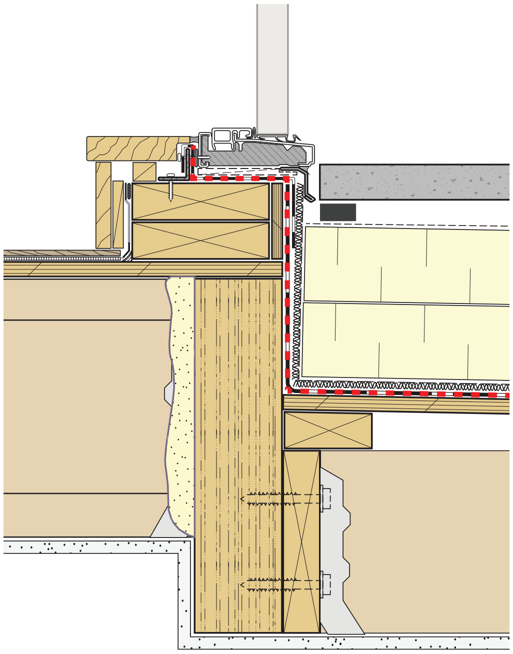
Vented roof deck with dropped framing and continuous waterproof roof membrane from door sill to curb/field membrane (red dash)

Deck Membrane

All roof decks must be designed and constructed as standard flat roofs. Torch-applied two-ply roofing systems generally offer the most robust approach. The roofing membrane should be applied to all areas, including the door sill where possible. Transition membranes such as liquid-applied polyurethane and bitumen-based waterproofing coatings can be used in difficult-to-access areas like beneath the door sill. The transition membrane must be compatible with the primary roofing membrane. Check with the AHJ for all materials used to confirm if they are acceptable in your area, and check that they are tested and rated as roofing products. All components should be installed according to the manufacturers' recommendations. All areas of membrane should be protected from traffic with both removable pavers that allow access to the roof membrane for inspection and maintenance, and flashing at curbs and upstands. Exposed membrane on a roof deck is not recommended.

Location of Insulation

Joist-insulated vented roof decks must include adequate ventilation from the perimeter of the roof deck. This can be difficult if the deck is enclosed with walls on all sides. An inverted roof that does not require venting may be simpler, but its placement must account for the height of the exterior insulation and door access.



Inverted roof deck with dropped framing and continuous waterproof roof membrane from door sill to curb/field membrane (red dash)

Air Barrier Continuity

For roof decks with an interior air barrier, the air barrier transitions between the door assembly, the polyethylene and framing below the sill, through the spray foam down to the interior ceiling polyethylene. For exterior air barriers, the transition can be directly from the roof sheathing to the door sill and roof membrane.

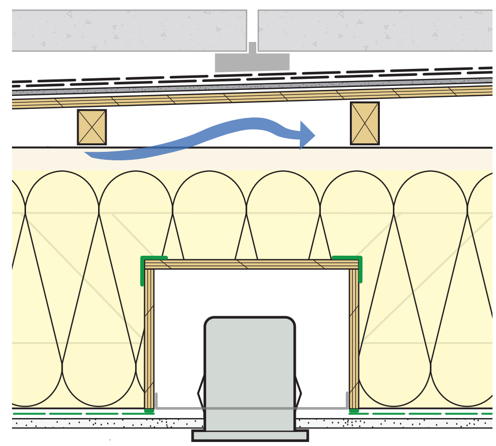
Ceiling & Roof Air Barrier Strategies

Ceiling and roof air barrier systems are usually of two conventional types: exterior air barrier systems, with the primary airtight elements placed at the exterior side of the roof sheathing, and interior air barrier systems, with the primary airtight elements installed at the interior side of the roof structure. Within these systems there are various approaches and components used to achieve the air barrier.

Exterior air barrier approaches use an airtight layer, usually a dedicated membrane, installed over the roof sheathing, and made continuous with tapes, membranes, and sealants over joints, transitions, and penetrations. The interior approaches use an airtight layer applied from the interior of the enclosure, interfacing with the various interior elements, transitions, and penetrations. The exterior approach is often simpler, because it does not interface with numerous interior elements like framing or service penetrations like pot lights. However, the exterior air barrier still must interface with interruptions at the outside of the building like plumbing stacks. The design and detailing must account for these challenges. In either approach, it is important that airtightness be provided at the interior side of the insulation

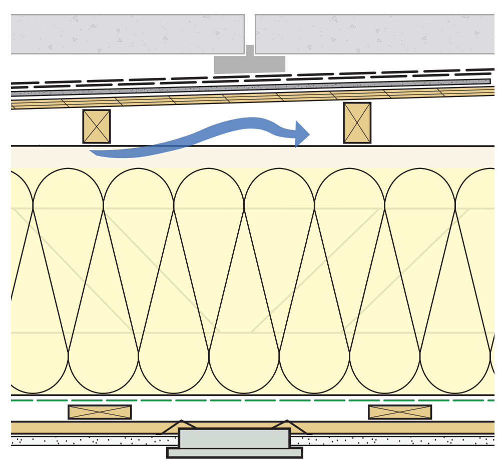
Ceiling Penetrations

Common ceiling penetrations such as pot lights and other electrical fixtures present a unique challenge to ceiling airtightness when an interior air barrier is used. There can be dozens of ceiling penetrations in a standard single family home or condominium, and each one is at risk of causing significant air leakage into and through the roof assembly. In many cases, the fixtures are installed after the ceiling drywall is in place, and the ceiling air barrier cannot be accessed from the interior side.



Airtight Service Box

For roof assemblies that use a dedicated interior air barrier material such as polyethylene or sheathing, dedicated airtight boxes should be used to create a continuous air barrier at each electrical penetration, before the ceiling drywall is in place. This is often done with a sealed OSB or plywood box, framed to allow the electrical wiring to be roughed-in and sealed, while still allowing room for the future fixture to be placed without affecting the air barrier. Note that deep pot lights may require additional framing to accommodate the depth inside the joist cavity and reduce the amount of insulation installed in those locations. Where possible, it is better to use shallow-depth light fixtures, such as LED puck lights, as placing insulation behind deep boxes can be difficult.

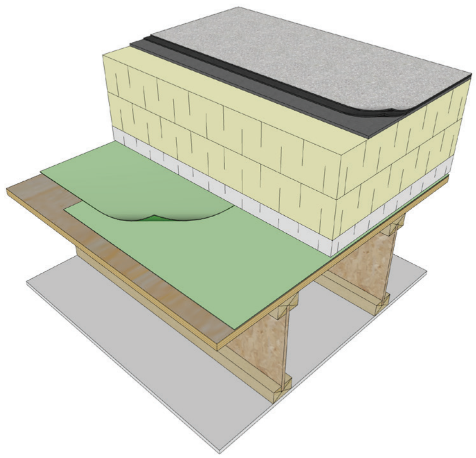


Ceiling Service Cavity

Instead of individual airtight boxes, a dedicated ceiling service cavity can be used at the interior side of the completed air barrier. This allows electrical and other services to run beneath the ceiling air barrier, and limits the penetrations through it. This approach is recommended where high-performance airtightness is required, and where many ceiling penetrations will be present. Ceiling service cavities can be framed using standard 1x or 2x framing, and cross-strapped if needed to allow uninterrupted access for running services across the ceiling.

Refer to the *Illustrated Guide - Achieving Airtight Buildings* and the *Energy Step Code Builder Guide,* published by BC Housing, for more detailed guidance on designing, constructing, and testing airtight roof assemblies (see Additional Resources on page 29).

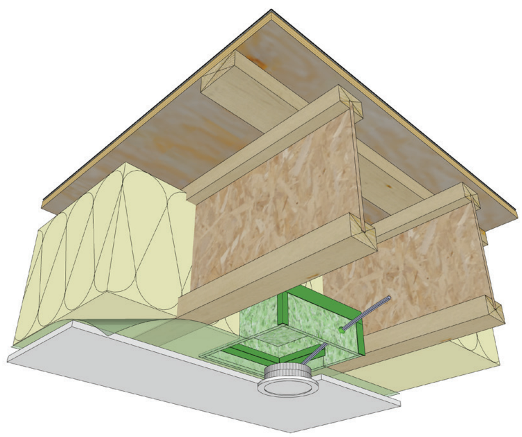
Air Barrier Systems



Exterior Sheathing Membrane Approach

Exterior Sheathing Membrane Approach

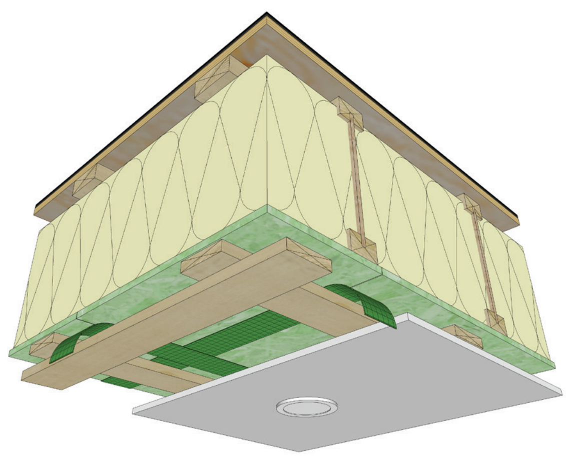
This approach uses a self-adhesive roof or torch-on sheathing membrane (over appropriate protection layer) as the primary air barrier element. Self-adhesive sheathing membranes rely on adhesion to both the substrate and at membrane laps. The membrane should be installed so that it is fully adhered to the substrate upon initial installation. Penetrations through the sheathing and membrane should be limited by using dedicated service openings that can be appropriately sealed. The air barrier should be reviewed for continuity before the remaining roof assembly components are installed over it.



Sealed Interior Polyethylene Approach

Sealed Interior Polyethylene Approach

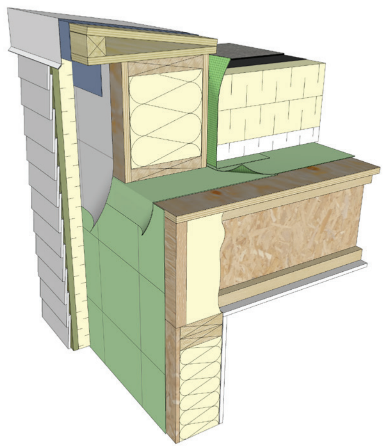
In this approach, polyethylene sheets are sealed at the interior framing to form the air barrier. All joints in the polyethylene are sealed and clamped between the framing and the interior finish (or service cavity framing). Airtight boxes, made from OSB or plywood with sealant or tape at edges, should be installed at all service openings. Rough-ins like cables should be installed and sealed at the airtight box. The various interfaces between the roof and interior elements such as partition walls, and the many penetrations at the ceiling, make the sealed polyethylene approach a difficult air barrier system to implement successfully. Therefore, it is not recommended for buildings where high performance airtightness is required, unless a service cavity is also installed.



Sealed Interior Sheathing Approach (with Service Cavity)

Sealed Interior Sheathing Approach (with Service Cavity)

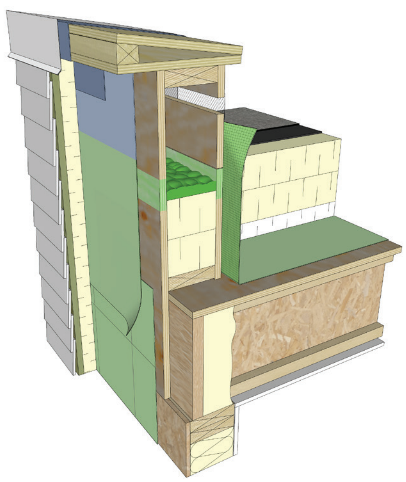
This approach uses an interior layer of sheathing as the primary air barrier element at the roof. The sheathing joints are sealed with tape or membrane strips, and the perimeter is set onto gaskets or sealant on the roof framing. Penetrations through the air barrier can be limited by using a service cavity framed inside the sheathing, where services can be run. This approach is a good option for joist roofs with insulation in the framing cavity, since the air barrier must be made fully airtight from the interior side of the enclosure, and the stiff sheathing substrate allows for robust detailing. The service cavity is an important component and should be included wherever possible.


Parapet Pre-Strip

Roof-to-Wall Air Barrier Transitions

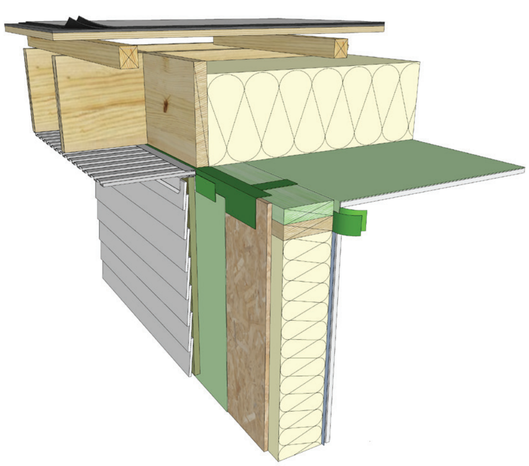
Parapet Pre-Strip

It can be difficult to transition an exterior air barrier system from the roof to the wall if there is a framed parapet in place at the roof perimeter. The pre-strip method uses an air barrier membrane strip beneath the parapet framing. The membrane provides a continuous air barrier uninterrupted by framing. This approach relies on the parapet being framed separately from the wall and roof framing. Any penetrations at the base of the parapet, including structural ties, must be carefully sealed to avoid air leakage into the parapet. The pre-strip method provides the simplest air barrier transition at the flat roof-to-wall detail.


Parapet Spray Foam

Parapet Spray Foam

Where the parapet must be framed in conjunction with the roof framing, the air barrier may have to pass through the parapet framing cavity. Closed-cell spray foam can be installed in each stud cavity between the two interior faces of the parapet sheathing. The sheathing and self-adhered membranes on either side of the parapet become part of the air barrier transition. Note this configuration should include parapet venting where possible. This approach requires coordination between the framing work and insulation, because the insulation fill and spray foam must be installed before the upper portion of the roof-side parapet sheathing is installed. The parapet spray foam approach is not a simple air barrier transition and should be carefully considered.

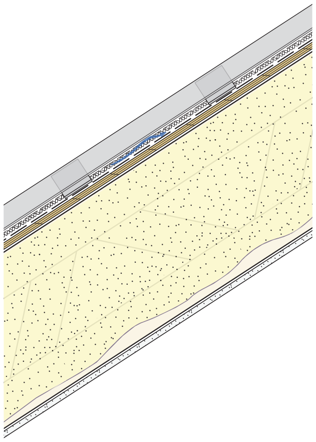

Taped Top Plate

Taped Top Plate

The air barrier transition between the interior ceiling air barrier and the exterior wall air barrier is achieved with tape at the exterior and interior perimeter and at all joints and intersections in the top plate. This approach creates a continuous air barrier at the top plate, and does not require any pre-stripping or sealant work while the wall is framed. Although the tape must be applied before the roof framing is placed, it allows for separation between the framing work and the air barrier transition work. This simplifies the task and allows for better quality control of the air barrier system. The tape used in this method should be high-performance sheathing tape.

Top-Side Vented Vaulted Spray Foam Roof

This assembly is designed with the roof ventilation at the top side of the sheathing between the roof covering (metal roof shown) and the water-resistive barrier. Cross-strapping or drainage mat (as shown) is installed under the roof covering. This assembly is well-suited to vaulted spray foam roofs where ventilation may not otherwise be possible. As shown in the roof assemblies below, this approach (when using cross-strapping) can be used with standard roof coverings like shingles as well. It is important that the sheathing membrane used beneath the ventilation space be vapour permeable, to allow potential drying of the sheathing to occur.



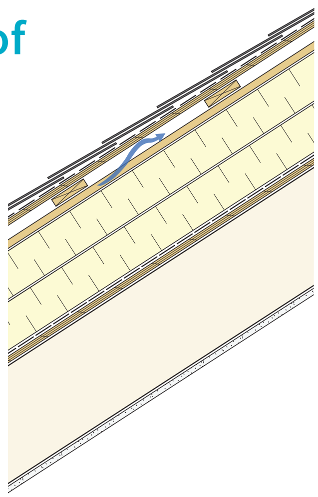
Exterior

- Standing seam metal roofing
- Drainage mat
- Vapour permeable sheathing membrane
- Roof sheathing
- Insulation in roof joist cavity (spray foam shown)
- Gypsum board

Interior

Exterior-Insulated Vaulted Roof

This assembly is designed with the insulation entirely above the roof structure. Purlins are installed to provide cross-ventilation, and exterior wood decking, underlayment, and shingles can be installed as in a common vaulted roof. This assembly is durable and offers redundancy against moisture penetration, as any moisture that penetrates the roofing can be drained at either the top of the rigid insulation or at the sheathing membrane at the primary roof sheathing below. This assembly also allows simpler transition between the exterior wall air barrier and the roof air barrier.



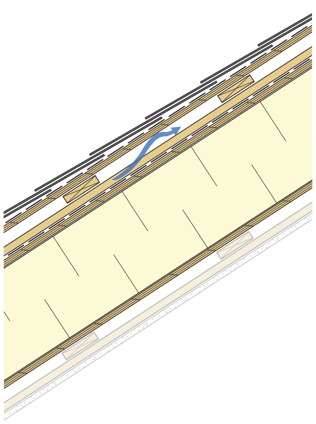
Exterior

- Shingles
- Underlayment
- Roof sheathing
- Air space at cross-strapping
- Rigid insulation (offset between layers)
- Self-adhered impermeable membrane
- Roof sheathing
- Empty roof joists
- Gypsum board

Interior

Structurally Insulated Panel Vaulted Roof

This assembly consists of manufactured structurally insulated panels (SIPs) made from continuous rigid insulation laminated between two layers of OSB sheathing. The panels are assembled to form the structural element of the roof. Addressing the joints between panels with respect to construction tolerances and air barrier continuity is an important consideration when using this system, and manufacturers should provide relevant details. Joints should be sealed on both the interior and exterior and the gap filled to prevent additional heat loss through convective looping between panels.



Exterior

- Roof covering (shingles)
- Underlayment
- Sheathing
- Air space at cross-strapping
- Vapour permeable sheathing membrane
- Structurally Insulated Panel
- Service cavity (recommended)
- Gypsum board

Interior

Maintenance & Inspections

Regular inspection and maintenance is needed to reduce the likelihood of premature leaks and aging. Roofs are exposed to sunlight, rain, snow, hail, wind, and temperature changes that gradually break down the roofing materials. Eventually, the replacement of the roof will be necessary; however, with proper maintenance and care, the service life of the roof can be maximized.

Roofs should be checked at least twice a year: in the spring to address any winter damage that may have occurred, and in the fall to prepare for the upcoming winter snow and rain. Gutters, drains, and scuppers should be reviewed at least annually, and more detailed roof maintenance should be completed at least every two years. For large or highly sloped roofs, maintenance should be done by a roofing professional or contractor, as it involves specialized knowledge, equipment, training, and safety requirements. A roof inspection and maintenance plan should be developed and should include checklists identifying the important areas to review and the frequency of reviews. As maintenance tasks are undertaken, a record should be kept and updated throughout the service life of the roof.

Life expectancies of roofs can range from 10 years to over 30 years, depending on the roof design, exposure, construction and materials used. Roofs should be replaced before the likelihood of significant failure gets too high, to avoid potentially costly damage from water leakage.

The following table lists common roof maintenance and inspection items that should be reviewed during each roof inspection.

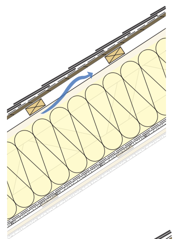
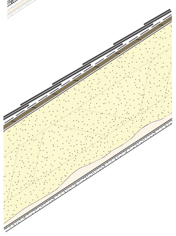
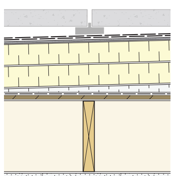
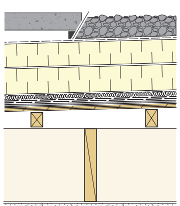
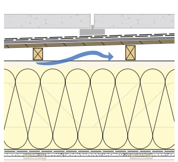
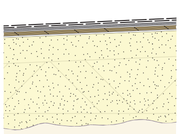
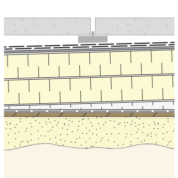
Vaulted Roof Checklist

Inspection/Maintenance Item	Description
Curled, broken, cracked or missing shingles	Repair the damaged areas immediately.
Missing granules on asphalt shingles	Aging, excessive foot traffic, and wind scouring caused by tree branches located too close to the roof are potential causes.
Excessive moss or algae growth	Moss and algae hold moisture on your roof that can lead to premature failures of shakes and shingles on vaulted roofs.
Foreign objects or build-up of debris/leaves/ vegetation (for non-green roofs) on roof	All debris should be removed to avoid damage and clogging of drains.
Overflowing eavestroughs or backed-up downspouts	Gutters and downspouts must be inspected and cleared regularly. Consider trimming nearby trees back to reduce debris build-up.
Missing or damaged flashing, eavestroughs, downpipes, sealants, and drain baskets	These items are all vital to the roof performance and should be repaired or replaced immediately to avoid larger problems. Caulking of flashings must be regularly inspected and maintained.
Staining or damage on the ceiling or walls	Act immediately to locate and repair any potential roof leaks.
Exterior review for signs of moisture penetration/accumulation	For unvented spray foam roofs, exterior review may be the only way to detect potential moisture accumulation issues, using visual inspection, physical force, and thermal imaging to locate wet roof sheathing.

Flat Roof Checklist	
Inspection/Maintenance Item	**Description**
Splitting, ridging, or blistering of the roof membrane	Typically caused by stress and aging, which can occur throughout the roof area. Seek professional roof repair assistance.
Missing gravel (ballast) on low-slope roofs	Ballast is needed in all areas to protect the membrane from damage and retain the insulation. If ballast is sparse or missing in areas it should be replaced as soon as possible.
Standing water (ponding on the roof)	Typically caused by blocked or poorly located drains. This water will accelerate the degradation of roofing membranes if left in place. Unclog drains to facilitate drainage. If water continues to pond, seek professional roof repair assistance.
Paver pedestals on roof membrane	Paver pedestals may create point-loads on roof membranes and cause localized damage of roof membrane. Therefore, the waterproofing membrane below areas of the roof that may be subject to excessive foot traffic should be reviewed annually. Consider placing paver pedestals on small pads or blocking to limit abrasion of the roof membrane surface.
Excessive moss or algae growth	Moss and algae hold moisture on your roof that can lead to premature failures of certain types of membranes on flat roofs.
Foreign objects or build-up of debris/leaves/ vegetation (for non-green roofs) on roof	All debris should be removed to avoid damage and clogging of drains.
Overflowing eavestroughs or backed-up downspouts	Gutters and downspouts must be inspected and cleared regularly. Consider trimming nearby trees back to reduce debris build-up.
Overflowing scuppers or overflow pipe	If the roof overflow drains are active, this is an indication that the primary roof drains are potentially blocked. Seek professional roofing/plumbing assistance for clearing drains.
Staining or damage on the ceiling or walls	Act immediately to locate and repair any potential roof leaks.
Exterior review for signs of moisture penetration/accumulation	For unvented spray foam roofs, exterior review may be the only way to detect potential moisture accumulation issues, using visual inspection, physical force, and thermal imaging to locate wet roof sheathing.

Summary of Roofs

Detailed discussions of each assembly, including thermal performance values, have been provided throughout the guide. This section provides a summary of the minimum insulation levels required for each assembly to achieve R-30 effective as well as key considerations for ease of reference.

			Min. Insulation Levels to Achieve R-30 Effective	Key Considerations
Vaulted	Vented		2x12 joists with 10" of R-3.4/inch batt insulation 9.5" I-joists with 8.5" of R-4/inch batt insulation	Besides good roof detailing and watertightness, the performance of the assembly depends on a combination of adequate roof venting and airtightness of the ceiling.
Vaulted	Unvented		2x10 joists with 8.25" of R-6/inch spray foam 9.5" I-joists with 9.5" of R-3.7/inch spray foam	The performance of the assembly depends on airtightness of the ceiling and more importantly good roof detailing and watertightness, including possibly the use of a more robust roofing system such as standing seam metal panel.
Flat	Conventional		7" of R-4/inch rigid insulation 6" of R-5/inch rigid insulation 5" of R-5.6/inch rigid insulation	An EPS sloping package installed with the roof insulation is often the simplest way to achieve required sloping. Multiple insulation layers should be offset in two horizontal directions to provide a continuous thermal insulation layer.
Flat	Inverted		6" of R-5/inch rigid insulation	The waterproof membrane is protected from loading and therefore can have a longer service life than membranes placed in more exposed environments. The assembly is difficult to maintain and repair because access to the membrane requires removal of the ballast and insulation.
Flat	Vented		2x12 joists with 10" of R-3.4/inch batt insulation 9.5" I-joists with 8.5" of R-4/inch batt insulation	Difficulty in achieving adequate venting, sensitivity to interior air leakage, and an assembly configuration where water can be trapped inside undetected puts this roof assembly at a higher risk of long-term performance issues.
Flat	Unvented		2x10 joists with 8.25" of R-6/inch spray foam 9.5" I-joists with 9.5" of R-3.7/inch spray foam	The performance of the assembly depends on air tightness of the ceiling and more importantly good roof detailing and watertightness, including around drains and penetrations.
Flat	Split-Insulated		R-24 nominal insulation on the exterior + R-12 nominal interior cavity insulation	To reduce the risk of condensation moisture within the roof assembly, the split-ratio of insulation should be 2:1 to include two-thirds of the nominal R-value on the exterior side, and the remaining one-third of the insulation between the roof joists. Otherwise, a hygrothermal analysis should be completed.

Design Guides

- *BC Energy Step Code—Design Guide* by BC Housing
(Available at www.bchousing.org)
- *Illustrated Guide—Achieving Airtight Buildings* by BC Housing
(Available at www.bchousing.org)
- *Illustrated Guide—Energy Efficiency Requirements for Houses in British Columbia* published by BC Housing
(Available at www.bchousing.org)
- *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings* published by FP Innovations, BC Housing, and the Canadian Wood Council
(Available at www.fpinnovations.ca)
- *Building Envelope Guide for Houses* published by BC Housing
(Available at www.bchousing.org)
- *Building Enclosure Design Guide* published by BC Housing
(Available at www.bchousing.org)
- *Canadian Home Builders' Association Builders' Manual* published by the Canadian Home Builders' Association
(Available at www.chba.ca/buildermanual.aspx)
- *Residential Construction Performance Guide* published by BC Housing
(Available at www.bchousing.org)
- *Builder's Guide to Cold Climates* published by Building Science Corporation
(Available at www.buildingsciencepress.com)
- *Pathways to High-Performance Housing in British Columbia* published by FPInnovations
(Available at www.bchousing.org)
- *Roof Maintenance Guide* and *Roofing Practices Manual* by Roofing Contractors Association of BC
(Available at www.rcabc.org/technical/)

Technical Information

- *Building Envelope Thermal Bridging Guide* published by BC Hydro and BC Housing
(Available at www.bchydro.com)
- *ASHRAE Handbook of Fundamentals 2013* published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).
(Available at www.ashrae.org)

Building Codes

- *Vancouver Building By-law (VBBL) 2014* published by the Queen's Printer for British Columbia
(Available at http://vancouver.ca/your-government/vancouver-building-bylaw.aspx)
- *British Columbia Building Code (BCBC) 2018* published by the Queen's Printer for British Columbia
(Available at http://www.bccodes.ca/index.html)

Research Centre
1701 – 4555 Kingsway
Burnaby, BC V5H 4V8
Phone: 604 439 4135
Toll-free: 1 866 465 6873
Email: technicalresearch@bchousing.org
www.bchousing.org

BC Housing's Research Centre works in collaboration with housing sector partners to foster excellence in residential construction and find innovative solutions for affordable housing in British Columbia. Sharing leading-edge research, advances in building science, and new technologies encourages best practice. The Research Centre identifies and bridges research gaps to address homelessness, housing affordability, social housing challenges and the needs of distinct populations. Mobilizing knowledge and research expertise helps improve the quality of housing and leads to innovation and adoption of new construction techniques, Building Code changes, and enhanced education and training programs. Learn more about the Research Centre at www.bchousing.org. Sign up to receive the latest news and updates at www.bchousing.org/subscribe.