Illustrated Guide

Insulated Wood-Frame Vaulted and Flat Roofs

for Residential Construction in British Columbia

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This guide is a new edition of the previously titled *Illustrated Guide: R30+ Effective Vaulted & Flat Roofs in Residential Construction in British Columbia*, published by BC Housing.

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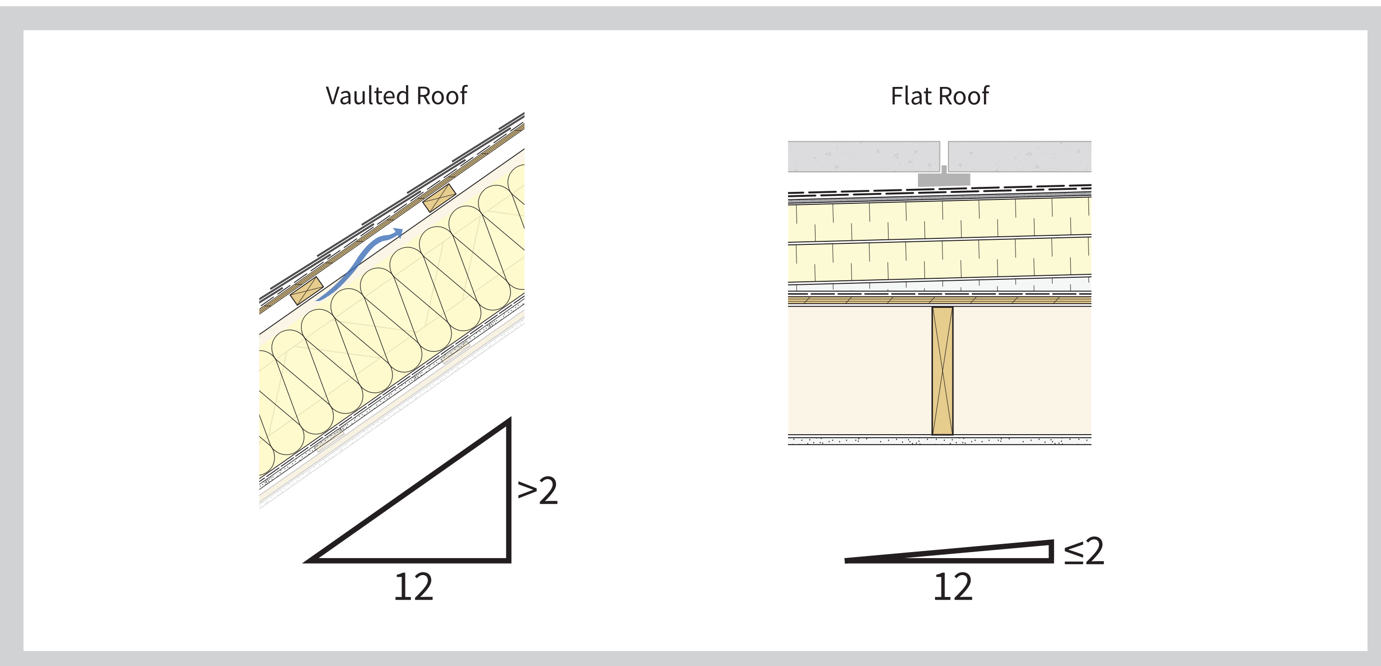
About this Guide

This Illustrated Guide consolidates information on vaulted water-shedding roofs and flat waterproof membrane roofs that are capable of meeting high effective thermal performance when used on low- and mid-rise wood-frame buildings. Increased thermal performance is necessary as part of energy performance improvements required by the BC Energy Step Code and the Vancouver Building Bylaw. This guide helps industry stakeholders meet higher thermal performance levels than previously needed, without 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, to a minimum of 1:50. Insulated vented attic and non-wood-frame roof assemblies are beyond the scope of this guide.

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. It is likely that these methods will need to be modified to accommodate variations in each project. Alternative assemblies exist beyond the scope of this guide.



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Building Enclosure Overview

The building enclosure is a system of materials, components, and assemblies that physically separate the exterior and interior environments. It includes 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 the 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 non-permeable 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 high effective thermal resistance while meeting the other performance requirements for roof assemblies. Insulated 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.

As with all Control Layers, the roofing system for any roof assembly type should be designed and installed according to the manufacturers' recommendations. For more information on roofing practices, materials, details and specifications, see the Roofing Contractors Association of BC (RCABC) website at www.rcabc.org.

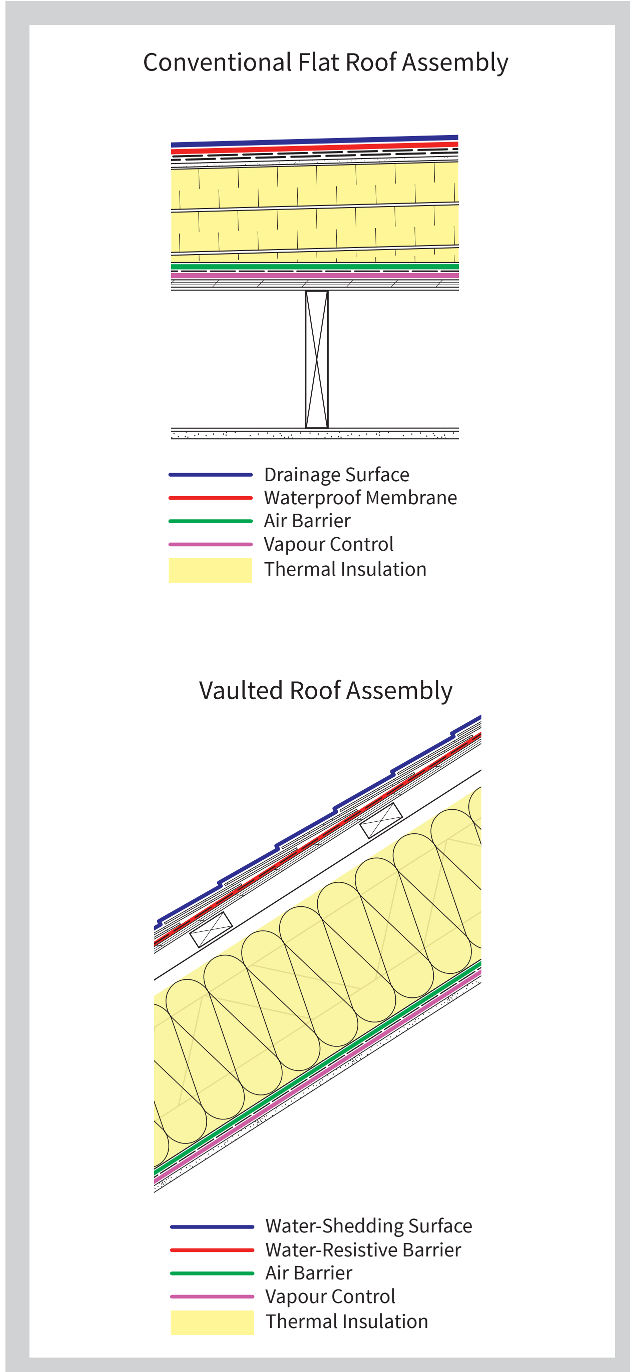


Figure 1-1 Roof assembly Control Layers

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 durable and efficient 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.

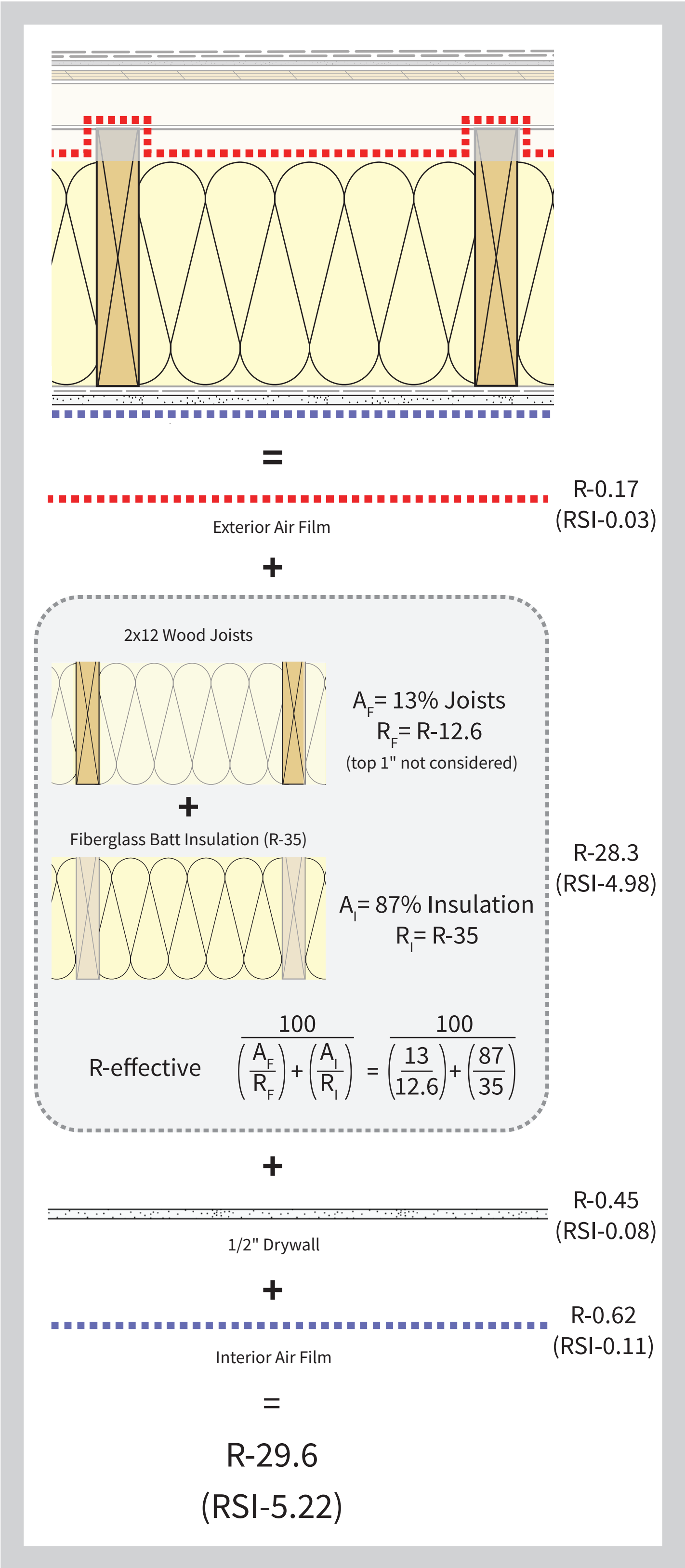


Figure 1-2 Example R-value calculation

R-value Calculations

The thermal resistance of building assemblies is commonly indicated using R-value, provided in imperial units of [ft^2·°F·hr/Btu], and can also be provided as RSI-value, in metric units of [m^2·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.

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

$$R = 1/U$$

For 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 Division B - Notes to Part 9, Note A-9.36.2.4.(1). 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 flat roof assembly is shown on the 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 Division B - Notes to Part 9, Note A-9.36.2.4.(1). 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.

Other R-value Calculation Methods

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 major code compliance and energy performance pathways in BC:

- Part 9 low-rise residential buildings - Refer to BCBC Division B, Section 9.36. Energy Efficiency (see previous page).
- Non-Part 9 Buildings in BC - Refer to BCBC Division B, Section 10.2 Energy Efficiency.
- Buildings in Vancouver - Refer to VBBL Division B, Section 10.2 Energy Efficiency.

For more guidance on R-value calculations and accounting for thermal bridging, refer to the various guides listed in 11 | Additional Resources on page 42.

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 R-value (R-average) between the minimum (R_{min}) and maximum R-value (R_{max}) does not accurately describe the effective thermal resistance of the insulation (see below). Instead, the effective R-value is calculated based on integrated area-weighted U-values as shown in the table below.

The logarithmic formula for effective R-value of rectangular tapered insulation is shown below (see Table A on the following page):

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

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

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

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)~~

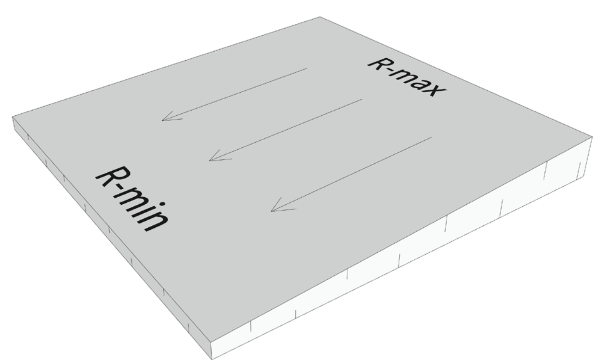


Figure 1-3 Comparison of average and integrated R-value calculations for rectangular tapered insulation (see also next page) and illustration of a tapered insulation board (right).

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

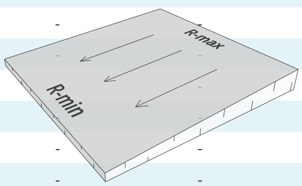
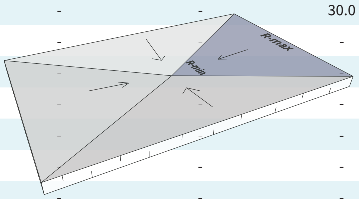


Table B: R-value calculation results for triangular tapered insulation

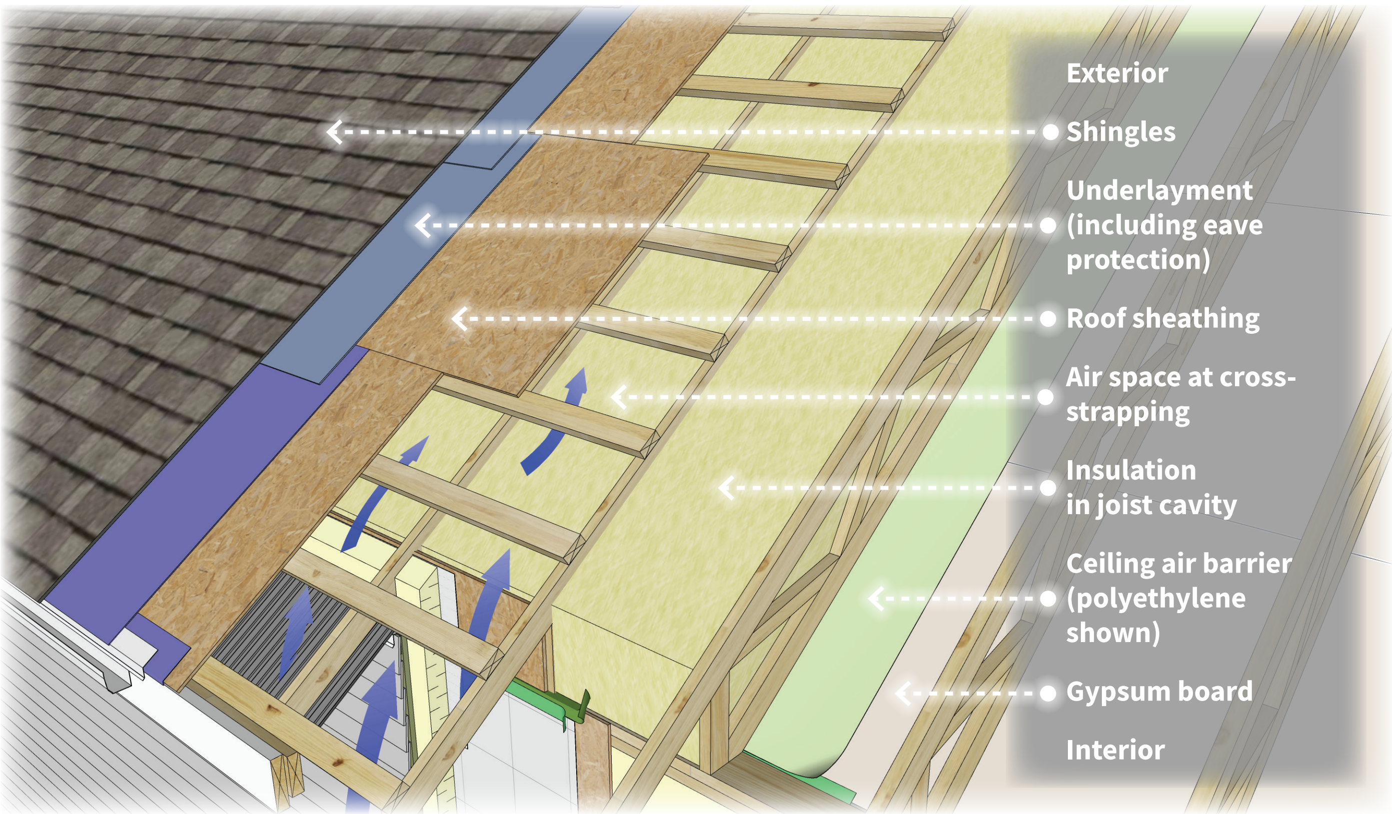
R_{min} ↓ / R_{max} →	20	25	30	35	40	45	50	55	60
4	13.4	16.1	18.8	21.5	24.2	26.8	29.5	32.1	34.7
5	13.9	16.7	19.5	22.2	24.9	27.6	30.2	32.9	35.5
10	16.3	19.3	22.2	25.1	27.9	30.7	33.5	36.2	39.0
12	17.1	20.2	23.1	26.0	28.9	31.8	34.6	37.4	40.2
14	17.9	21.0	24.0	27.0	29.9	32.8	35.6	38.5	41.3
16	18.6	21.8	24.9	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 suppliers | 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.

VR-1 | Joist-Insulated Vented Vaulted Roof

This vaulted roof assembly consists of insulated roof joists with venting beneath the roof sheathing. The depth of the insulation is limited by the depth of the roof joists, with allowance for venting. Engineered trusses can 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" venting clearance. The cross-strapping perpendicular to the joists provides venting 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. 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.
- An assembly configuration that can trap moisture undetected on the polyethylene, difficulty in achieving adequate venting, and sensitivity to interior air leakage, puts this roof assembly at a risk of long-term performance issues over the service life of the roof. Therefore, its use 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.

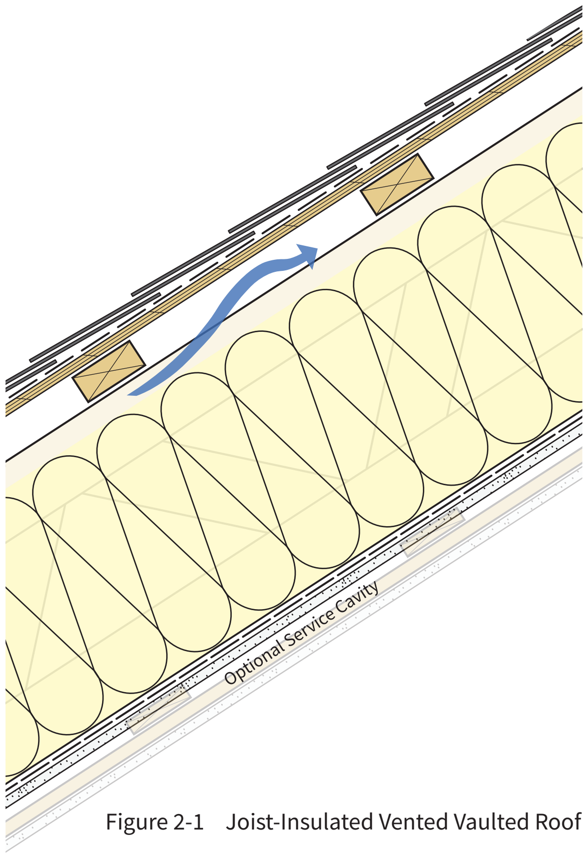


Figure 2-1 Joist-Insulated Vented Vaulted Roof

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

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 venting 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 7 | Airtightness on page 35 for more guidance on achieving good roof assembly airtightness.

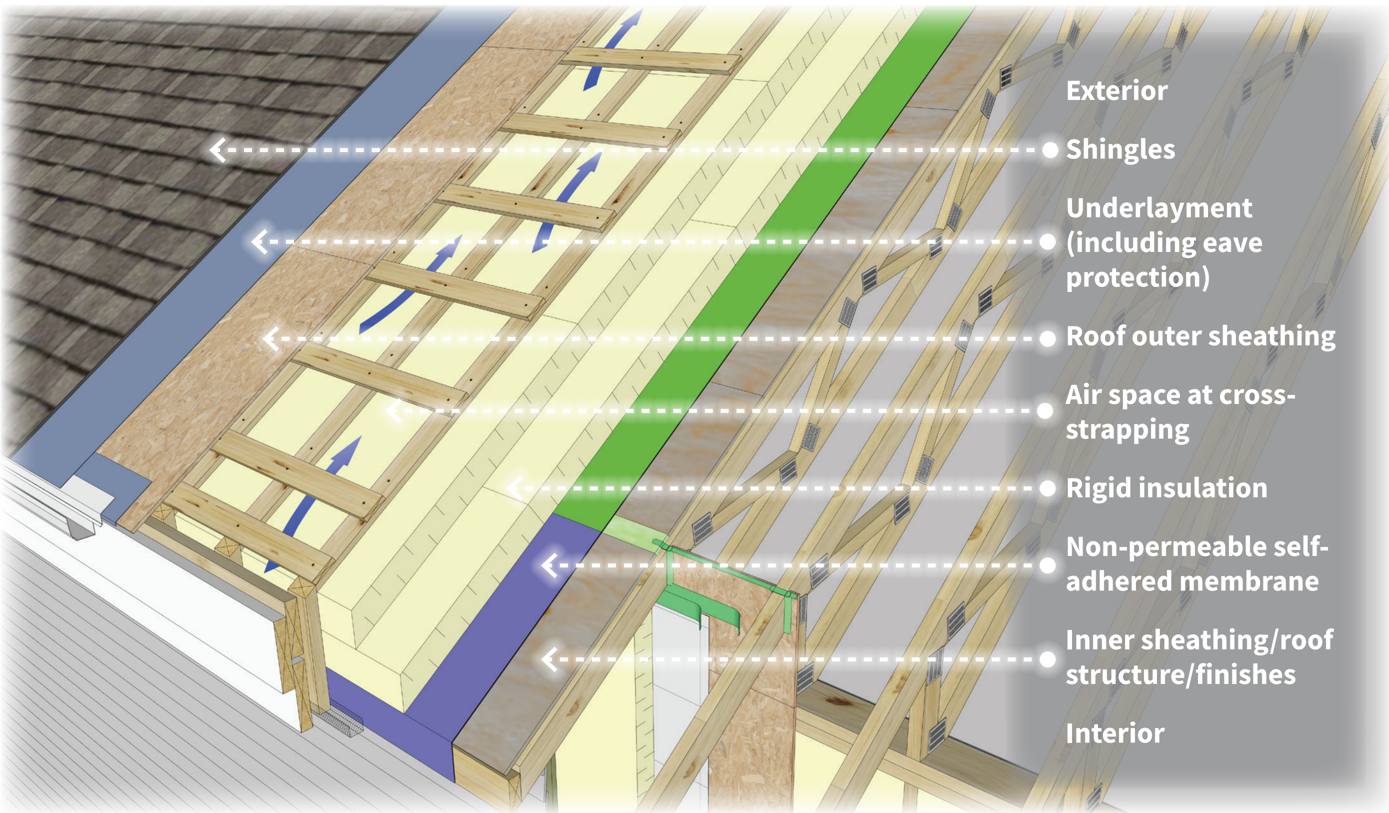
Roof colour plays an important role in the durability of the assembly. Dark grey or black roofs will reach higher temperatures when exposed to direct sunlight, compared to lighter-coloured roofing materials. This can lead to increased thermal stress on the material. However, higher temperatures provide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

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

*Components above the vented air space not accounted for. For assemblies with a 1.5" interior service cavity, add R-1.0 to the effective R-value.

VR-2 | Exterior-Insulated Vaulted Roof

This roof assembly consists of rigid insulation placed on the exterior of an uninsulated roof structure, with a secondary water resistive barrier on the primary (inner) roof sheathing. The depth of the exterior insulation is unaffected by the depth of the roof structure, meaning the insulation can be as thick as required and permitted by its structural attachment. High effective R-values of the assembly are achieved by using continuous insulation outside of the structural framing in combination with thermally efficient roof strapping attachments. In most cases, the outer roof sheathing and roofing materials can be supported by strapping fastened with long screws through the rigid insulation into the roof structure. A variety of different exterior insulation types can be used, including rigid stone wool and rigid foam board. See 4 | Vaulted Roof Exterior Insulation on page 28. Where needed, a venting space is provided beneath the roof's outer sheathing. Continuity of the air barrier at the inner roof sheathing is critical to the performance of this assembly. A unique butyl tape air sealing detail at the roof-to-wall interface is used to allow for conventional roof framing techniques.



Key Performance Items

- For conventional shingle and shake roofing products, it is best practice to provide venting at the eaves and the roof ridge, and cross-strapping such that air can reach all areas beneath the outer roof sheathing.
- Continuous roof slope is important to allow drainage, including melting snow. Long valleys with lower slopes should be avoided.
- The butyl tape and sealed blocking detail at the roof-to-wall interface is critical for the airtightness of this assembly. The approach requires careful sequencing of the roof framing and sheathing. See Roof-to-Wall Air Barrier Transitions on page 37.
- Multiple insulation layers should be offset in both directions to provide a continuous thermal insulation layer. This roof relies on the secure attachment of the rigid insulation for adequate wind uplift and gravity load resistance of all exterior assembly components.
- See 4 | Vaulted Roof Exterior Insulation on page 28.

Water Penetration Control

This assembly sheds all exterior water by gravity drainage. The sloped nature of the surface means that shedding and drainage capabilities are good, and the materials do not need to be resistant to a hydrostatic head of water. The roofing underlayment provides a second line of protection. High temperature underlayment may be required depending on the type of roofing and its colour. In assemblies with metal roofing, the underlayment is installed either directly on the exterior insulation or draped over the vertical strapping as shown (see right). For more guidance on metal roofing, underlayment and attachment see the Roofing Contractors Association of BC website at www.rcabc.org and their Standard for Architectural Sheet Metal Roof Systems. The self-adhered sheathing membrane on the inner roof sheathing provides a third layer of water penetration control, though its primary purpose is for air and vapour control.

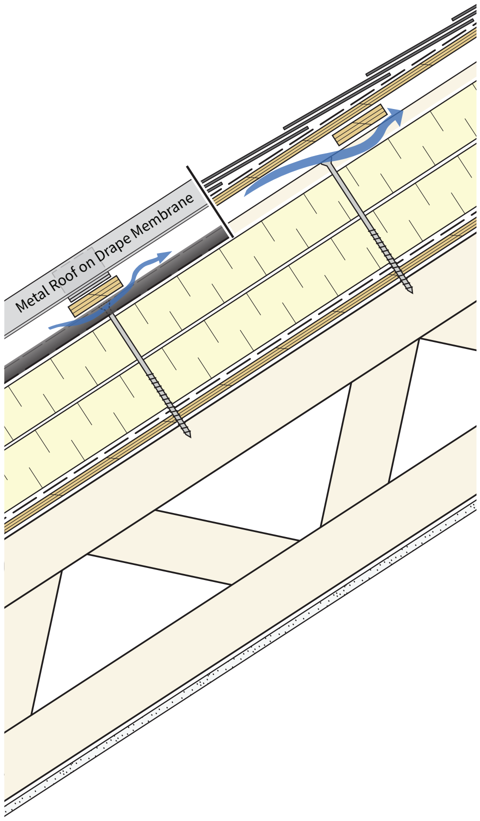


Figure 2-2 Exterior-Insulated Vaulted Roof

Air Barrier

A self-adhered sheathing membrane over the inner roof sheathing acts as the air barrier for this assembly. This membrane can be detailed both as airtight and watertight, and serves as a third line of protection from water ingress. Continuity of the air barrier at transitions and penetrations is critical to its performance. The air barrier in this assembly is placed above the roof framing, so penetrations in the ceiling finish do not affect the assembly airtightness. However, exterior service penetrations must be made airtight at the inner roof sheathing membrane prior to installing the exterior insulation and outer roofing components.

Insulation & Venting

Rigid stone wool and rigid foam board insulation such as expanded polystyrene (EPS) extruded polystyrene (XPS) and polyisocyanurate (polyiso) can be used for the exterior insulation. The insulation type should be chosen with consideration for the expected heat exposure, moisture load and thermal cycling the roof will experience. Some foam insulations are not suitable as roof insulation due to heat exposure melting risk. Insulation placed on the exterior of the inner roof sheathing increases the temperature of the moisture-sensitive wood sheathing and framing, reducing the risk of condensation and associated moisture damage and improving durability. Cross-strapping is typically installed to provide structural attachment for the exterior insulation and venting beneath the roofing. Metal roofs may use a geotextile ventilation/drainage mat directly beneath the roofing instead.

Effective R-values - Exterior Insulated Vaulted 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"

*Thermal bridging through the exterior insulation and cross-strapping attachment method is not accounted for.

Vapour Control

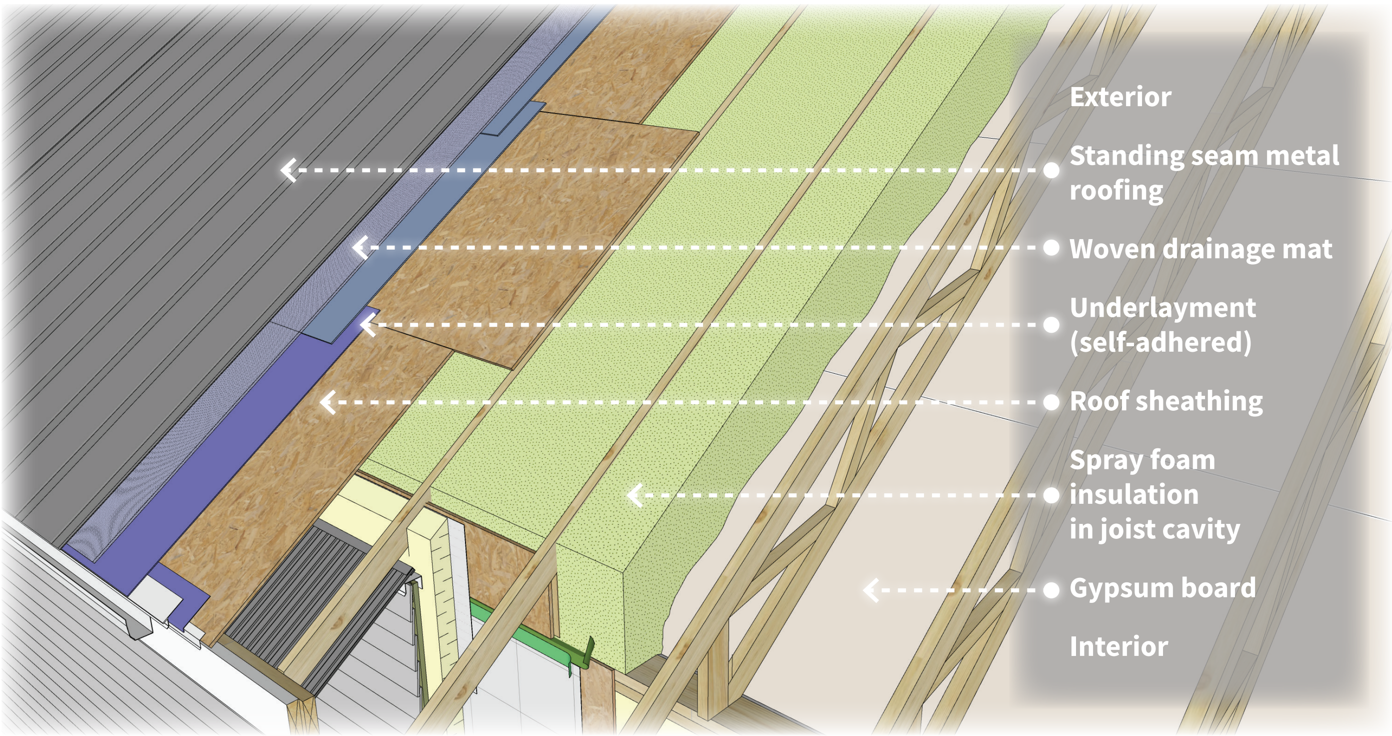
The self-adhered sheathing membrane at the inner roof sheathing provides the vapour barrier for control of outward vapour diffusion.

Design Considerations

The detailing and construction sequencing of the exterior self-adhered air barrier membrane must be carefully planned to avoid rework or components being covered before they are air sealed. See Roof-to-Wall Air Barrier Transitions on page 37. The design and installation of attachment system for the exterior insulation and roofing materials require careful attention to ensure long-term durability and structural integrity (see 4 | Vaulted Roof Exterior Insulation on page 28).

VR-3 | 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 venting within the joist space. 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 venting 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 for unvented roofs.
- As well as 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.
- Low-density spray foam insulation does not provide vapour control and must be used with a dedicated vapour retarder.
- 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.

Consider top-side venting on spray foam roofs | Sensitivity to interior air leakage, no venting 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. Therefore, top-side venting using purlins or thick cross-strapping is recommended especially if using conventional roof shingles. Regardless, this roof type relies on high-quality roof installation and timely maintenance and renewals over its service life. See 8 | Additional Roof Assemblies on page 38 for more information.

Water Penetration Control

This assembly sheds all exterior water by gravity drainage over shingled materials or metal roofing. 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. High temperature underlayment may be required depending on the type of roofing and its colour. Traditionally, asphalt-saturated organic underlayment has been used, but newer synthetic products are becoming more common and may be preferred. The assembly is sensitive to exterior moisture that penetrates at a roof leak location because no dedicated venting strategy is used and its drying capability is limited (see 5 | Spray Foam in Roofs on page 31). Therefore, an air space beneath the roofing is recommended, and a secondary sheathing membrane should also be considered for conventional shingle roofs.

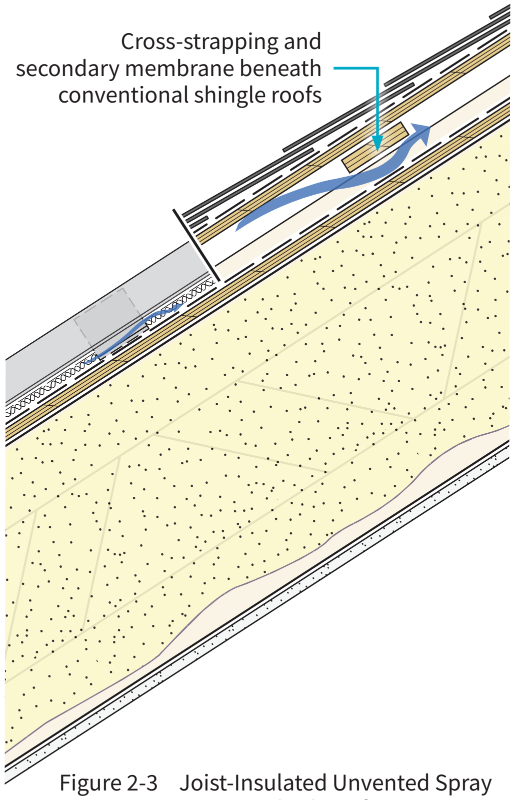


Figure 2-3 Joist-Insulated Unvented Spray Foam Vaulted Roof

Air Barrier

The foam and framing or roof sheathing may be considered the primary elements of the air barrier system in the field of the assembly. Pay special attention when applying foam in order to ensure correct installation with full adhesion to the substrates. Sealant or tape is still likely required at framing joints to maintain a continuous air barrier. Poor installation of spray foam may reduce the durability of the roof assembly.

Insulation

The joist spaces are typically insulated using open-cell, closed-cell, or hybrid open-cell spray foam. 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 can be installed to the full thickness of the joist cavity and trimmed flush, though it's use should be carefully considered (see 5 | Spray Foam in Roofs on page 31).

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

Vapour Control

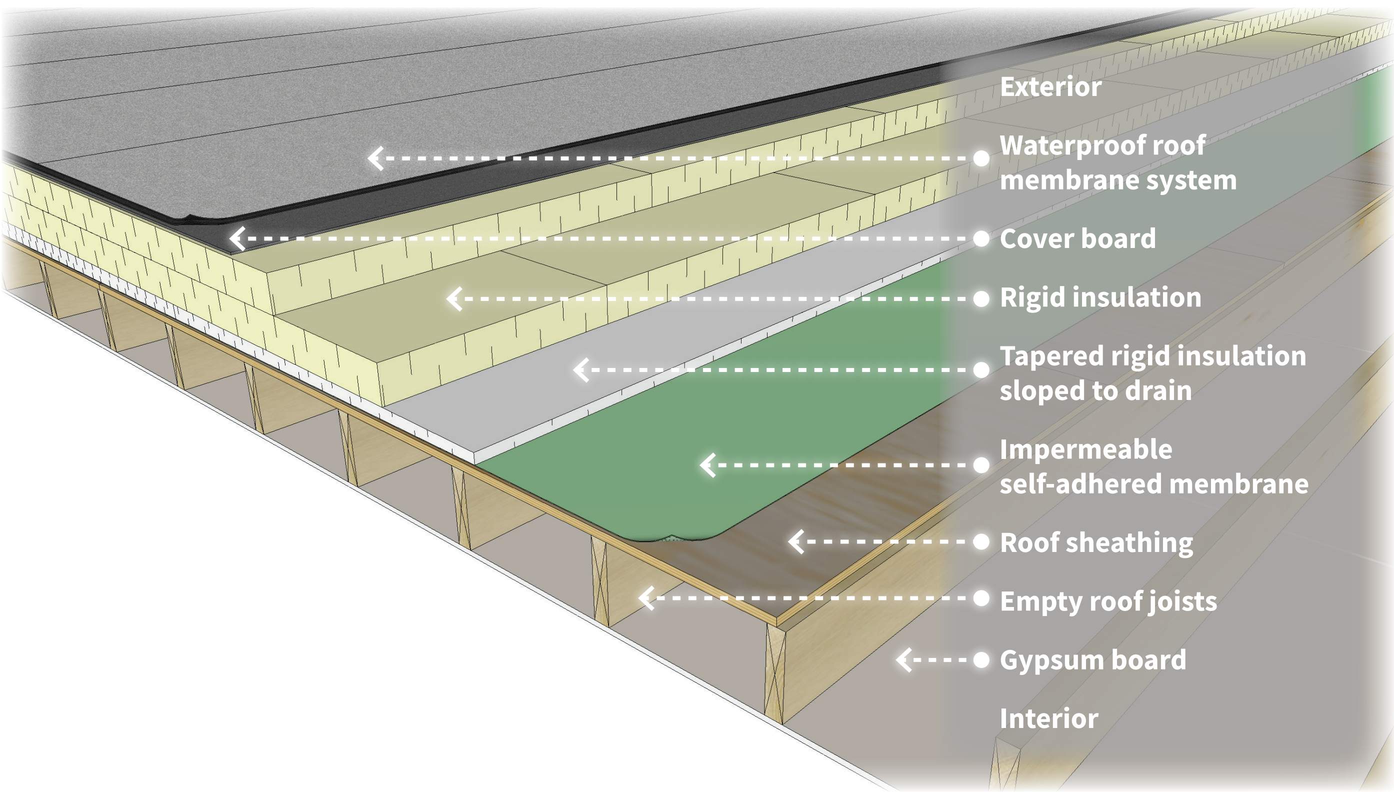
Closed-cell foams provide sufficient resistance to vapour diffusion, controlling the outward movement of interior moisture in most situations. Lighter density open-cell foams must utilize a dedicated vapour retarder at the interior (see 5 | Spray Foam in Roofs on page 31).

Design Considerations

Providing an air space beneath the roofing is a good way to manage the risk of moisture getting trapped in the assembly. While not considered traditional roof venting, it is still better than no venting at all. See 8 | Additional Roof Assemblies on page 38 for further guidance on providing top-side roof venting in a sloped roof.

FR-1 | 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 cover board, controls all exterior moisture. The adhered non-permeable sheathing membrane over the roof sheathing is used as the air barrier and vapour retarder. Venting of this assembly is not necessary. Various types of rigid board insulation can be used in this assembly. This assembly is sloped using the framing components or an insulation taper package.



Key Performance Items

- An EPS taper 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 both 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 cover 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, therefore regular top side inspection is necessary to detect leaks. Wood-frame flat roofs should use robust roofing systems and detailing. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

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.

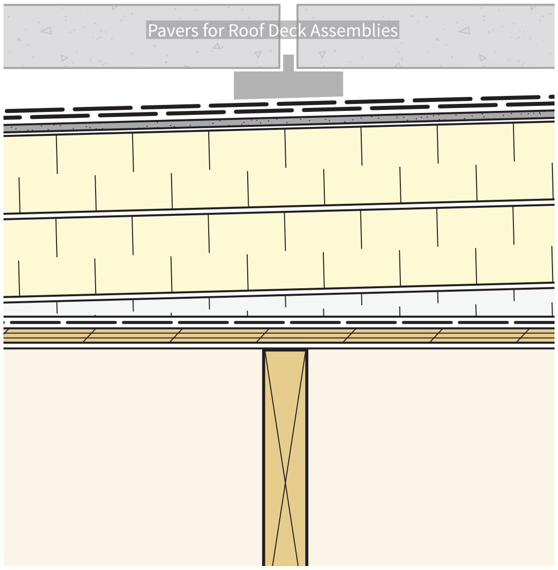


Figure 3-1 Exposed Membrane Conventional Flat Roof

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. Multiple insulation layers should be offset in both directions to provide a continuous thermal insulation layer. This assembly does not require venting above the insulation since it is all located above the roof sheathing and air barrier.

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"

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

Vapour Control

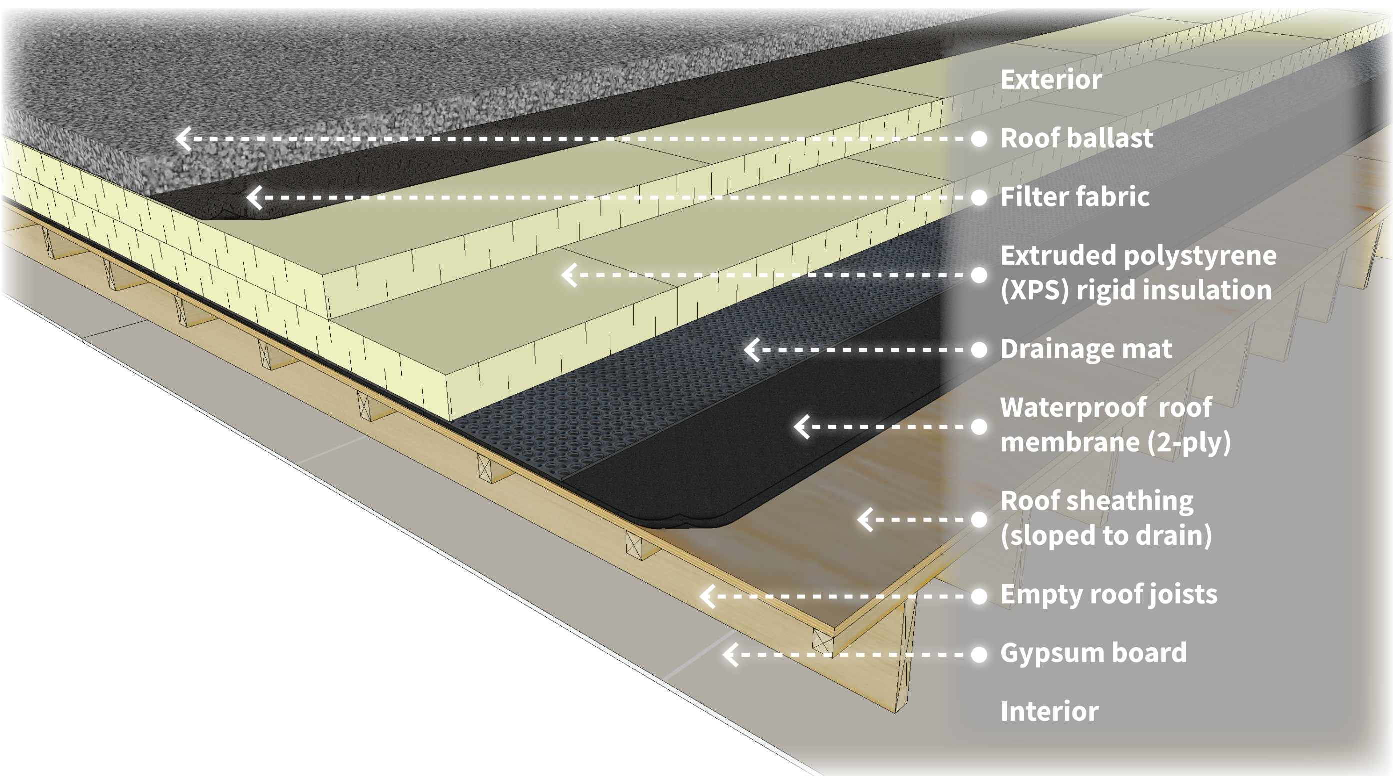
The roof sheathing and self-adhered vapour retarder membrane provide sufficient vapour resistance to control outward vapour flow, and are well located with all moisture sensitive components on the interior side of these layers. Note that rigid insulation is not considered a moisture sensitive material,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

Design Considerations

An EPS taper package installed with roof insulation (as shown) is often the simplest way to achieve the 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 6 | Roof Decks on page 33.

FR-2 | 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 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. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

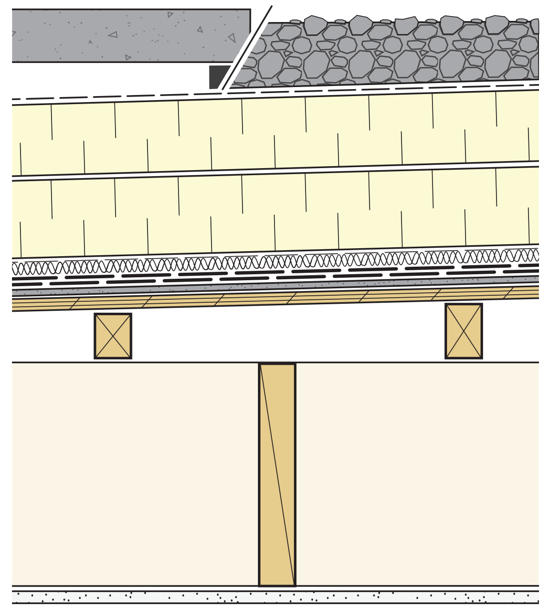


Figure 3-2 Protected Membrane Flat Roof

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. The insulation must be able to withstand exposure to water because the waterproof roofing membrane is located below the insulation. Multiple insulation layers should be offset in both directions to provide a continuous thermal insulation layer.

Effective R-values - Inverted 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"

*Thermal bridging through the exterior insulation from water flow is not accounted for.

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.

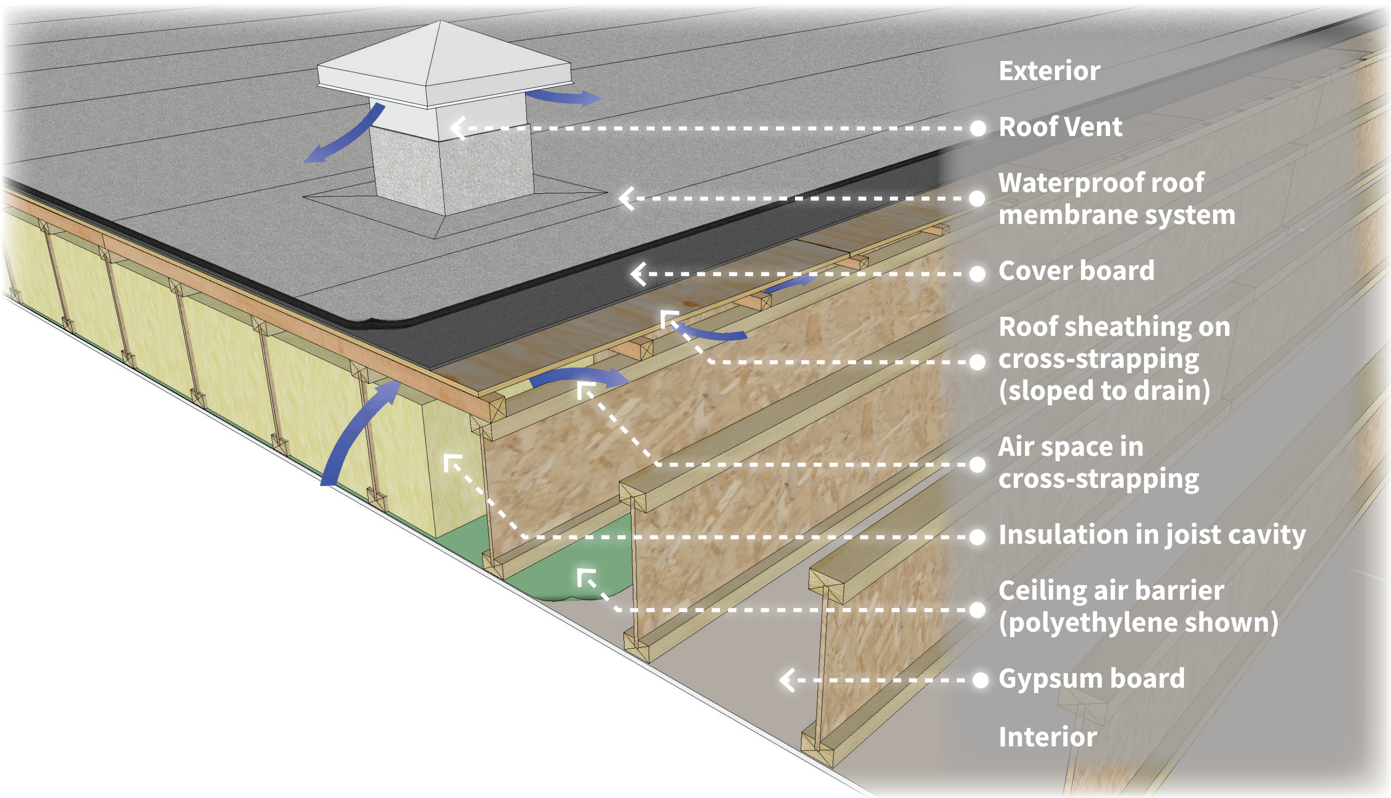
Design Considerations

Unlike a conventional roof assembly with tapered insulation for sloped drainage, the roof structure must be sloped or a taper 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 the insulation and the waterproof roof membrane | Water traveling below the insulation will absorb some heat from the building, which is lost when the water runs to the roof drains This can lead to a 5% R-value reduction and even higher depending on the assembly configuration. The European standard EN ISO 6946/A1, Section D.4.3. accounts for this loss with a correction to the U-value for the given roof assembly. The best way to reduce the thermal loss from water runoff in inverted roofs is to provide a drainage layer above the insulation. Accounting for this loss is typically not required to demonstrate code compliance.

FR-3 | Joist-Insulated Vented Flat Roof

This flat roof assembly consists of insulated roof joists with venting beneath the roof sheathing. The depth of the insulation is limited by the depth of the roof joists, with allowance for venting 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" venting 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.
- An assembly configuration that can trap moisture undetected, sensitivity to venting, and potential interior air leakage 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. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

Air Barrier

Sealed-polyethylene, airtight-drywall or other sealed interior ceiling approaches (see Ceiling & Roof Air Barrier Strategies on page 35) 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

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. An assembly configuration that can trap water undetected, difficulty in achieving adequate venting, and sensitivity to interior air leakage 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 venting 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.

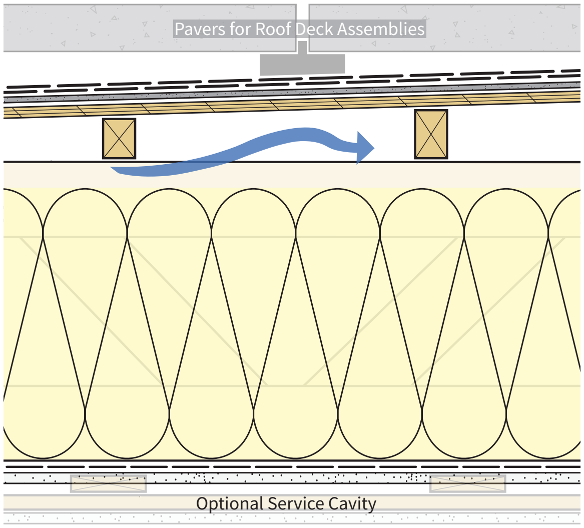


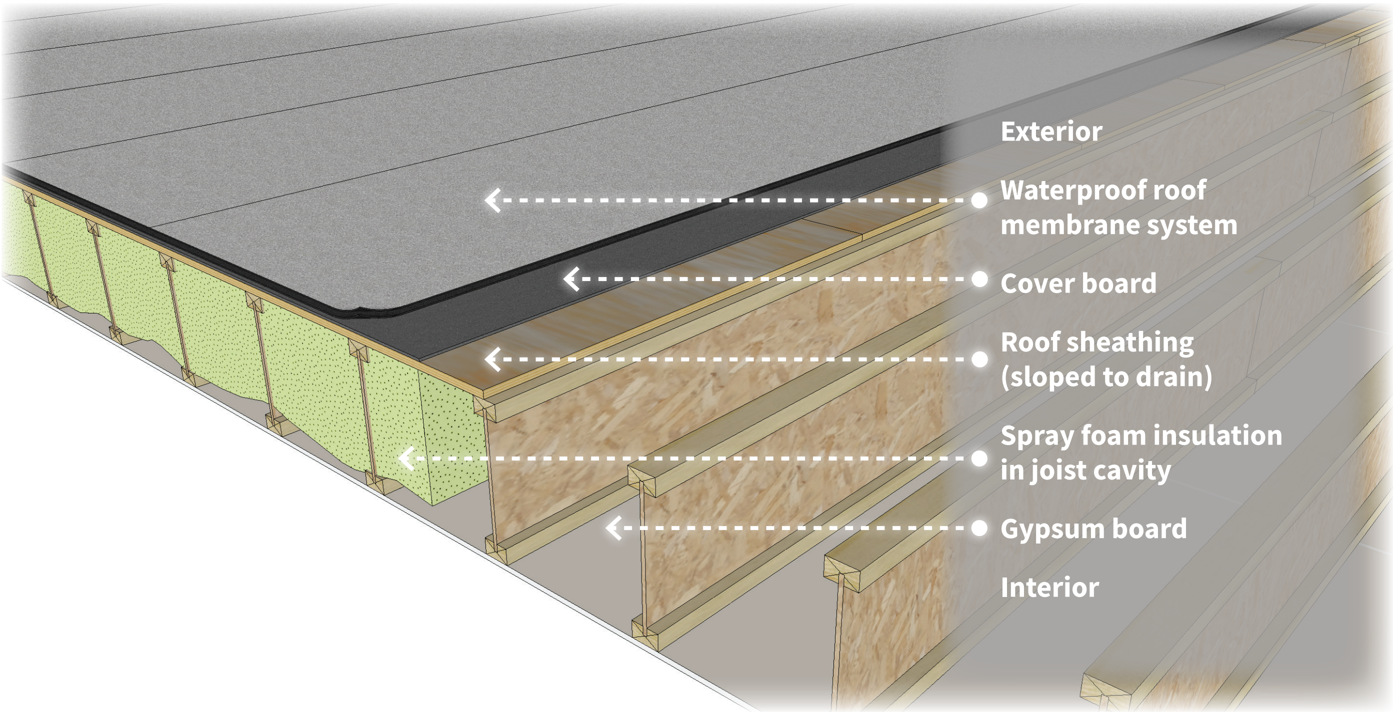
Figure 3-3 Joist-Insulated Vented Flat Roof

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

*All components above vented air space not accounted for.
For assemblies with a 1.5" interior service cavity, add R-1.0 to the effective R-value.

FR-4 | 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 venting. 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 venting 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. 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. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

Air Barrier

The foam and framing or roof sheathing may be considered the primary elements of the air barrier system in the field of the assembly. Special attention must be paid when applying foam in order to ensure correct installation with full adhesion to the substrates. Sealant or tape is still likely required at framing joints to maintain a continuous air barrier. Poor installation of spray foam may reduce the durability of the roof assembly.

Insulation

The joist spaces are insulated using open-cell, closed-cell, or hybrid open-cell spray foam. 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 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 can be installed to the full thickness of the joist cavity and trimmed flush, though its use should be carefully considered. See 5 | Spray Foam in Roofs on page 31 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 vapour 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 5 | Spray Foam in Roofs on page 31).

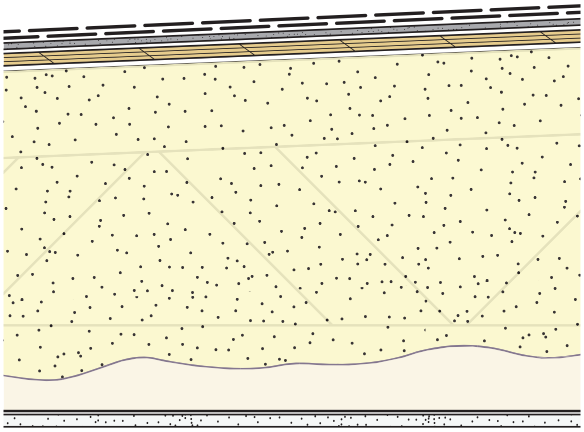


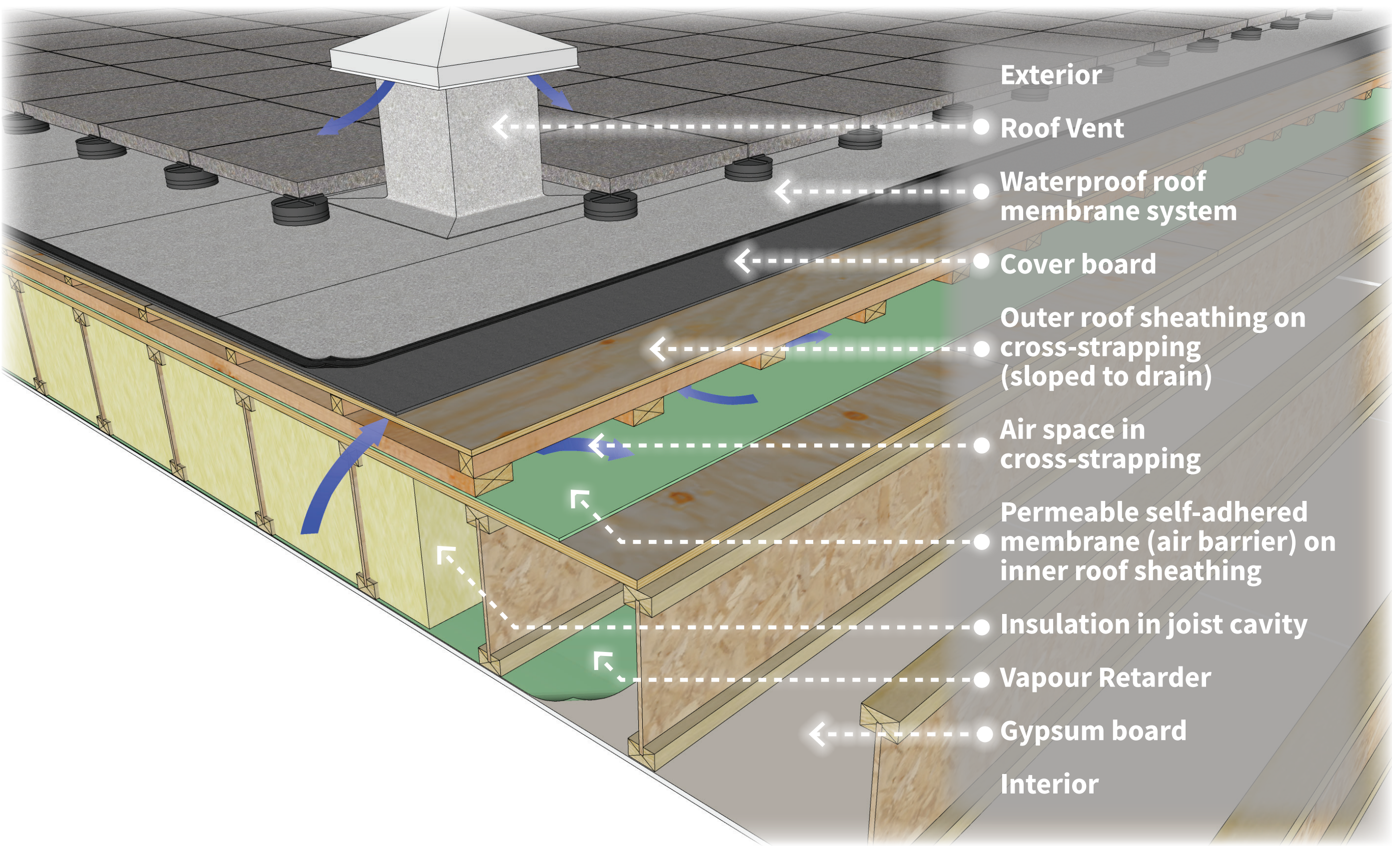
Figure 3-4 Joist-Insulated Unvented Flat Roof

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

FR-5 | Joist-Insulated Exterior Air Barrier Vented Flat Roof

This vented flat roof assembly consists of fully insulated roof joists with roof sheathing, an exterior air barrier membrane on the inner roof sheathing, and venting provided above the membrane beneath the outer roof sheathing. The depth of the insulation is limited by the depth of the roof joists, and may result in the assembly having relatively low thermal performance for a roof. Engineered trusses can be used to create a deep joist space for more insulation, but this may result in interior bulkheads or areas with lower ceilings. The joist space can be insulated using a variety of different insulation types. The assembly contains an exterior air barrier as well as flat inner roof sheathing and sloped exterior roof sheathing on sloped cross-strapping. Clearance for venting beneath the outer roof sheathing is provided by purlins (i.e., cross-strapping) 2.5" thick. A continuous exterior air barrier is a key component in this assembly and is discussed further in 6 | Roof Decks on page 33.



Key Performance Items

- Draining the roof deck 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 durable walking surface or robust walkable membrane are required for occupied roof deck applications.
- Sensitivity to venting and potential interior air leakage is best managed with a robust continuous exterior air barrier on the roof inner sheathing. While interior ceiling airtightness is beneficial, this assembly relies on the exterior air barrier and top-side venting as key to its performance.
- The assembly being entirely joist insulated may result in bulkheads at the ceiling plane to reach thermal performance targets.

Water Penetration Control

This assembly controls all liquid water at the waterproof membrane above the outer roof sheathing. The waterproof membrane and drainage surface are coincident. Water must drain over the membrane to centrally located drains or perimeter gutters and scuppers. The venting capability of this assembly below the exterior sheathing layer 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. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

Air Barrier

The primary air barrier system is located above the inner roof sheathing. This exterior air barrier is outside the primary structure of the assembly, simplifying detailing at intersecting wall assemblies and penetrations. The air barrier membrane is vapour open to allow the assembly to dry upwards into the venting space if needed.

Insulation & Venting

Stone wool, fiberglass batt, blown-in fibrous insulation (i.e., cellulose or fiberglass), or spray foam can be used to insulate the joist space. The roof assembly R-value is based on the depth of joist and spacing. A venting space is provided by cross-strapping above the air barrier membrane beneath the outer roof sheathing.

Vapour Control

Polyethylene, vapour retarder paint, or a smart vapour retarder, can provide control of outward vapour flow. Despite the exterior air barrier and top-side venting, the roof assembly can be difficult to vent, sensitive to interior air leakage, and at risk of trapping water inside the joist space. 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 exterior roof sheathing as a result of moisture in venting 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 also provide drying benefits that could make the assembly more durable.

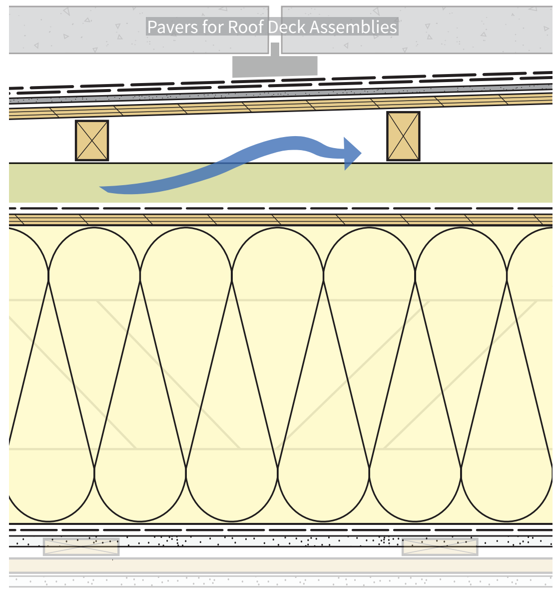


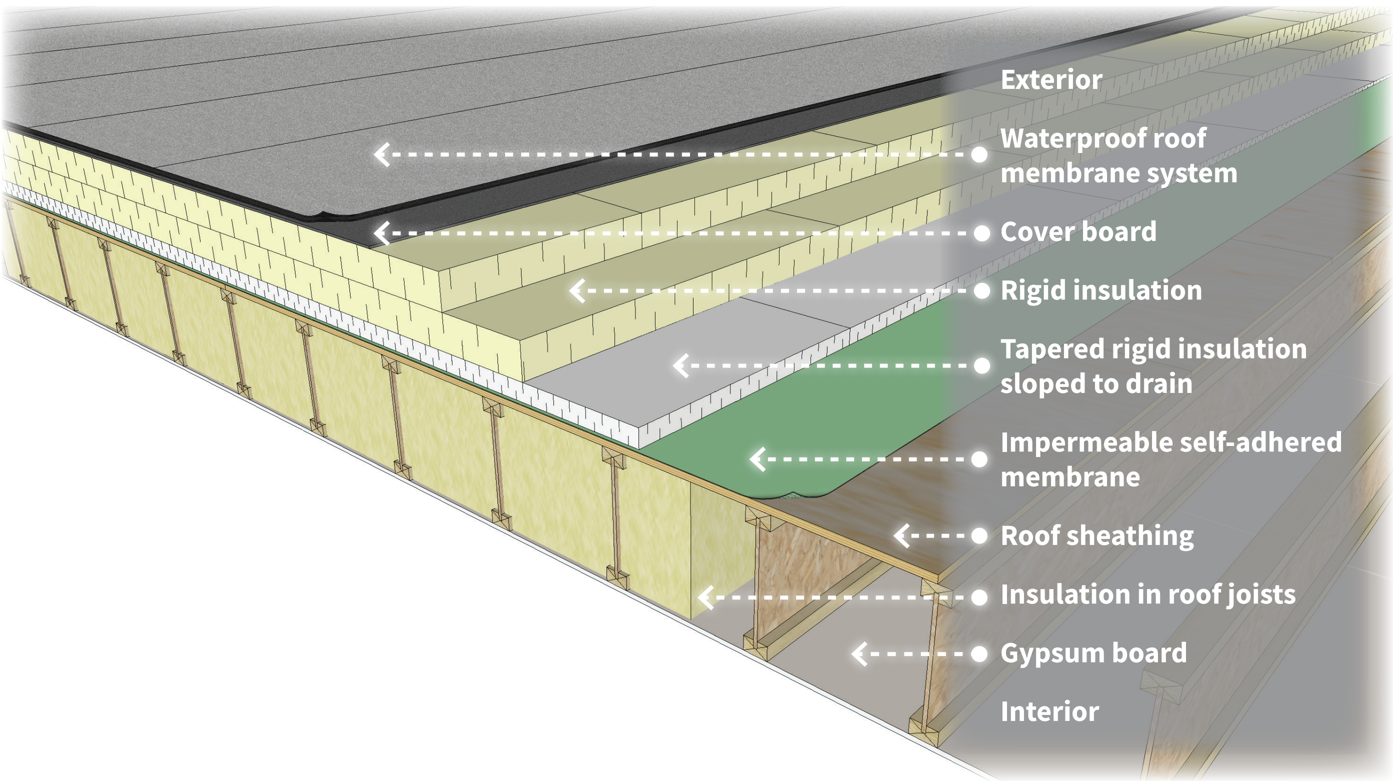
Figure 3-5 Joist-Insulated Top-side Vented Flat Roof

Effective R-values - Vented Flat Roof [ft² •°F•hr/Btu]*				
2x Framing				
Framing Depth	Without Service Cavity		24" o.c.	
	R-3.4	R-4.0	R-3.4	R-4.0
2x8 (7¼")	21.9	24.3	22.9	25.2
2x10 (9¼")	27.4	30.5	28.4	31.4
2x12 (11¼")	32.9	36.6	33.9	37.6
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

*Components above the vented air space not accounted for.

FR-6 | 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, and 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 cover 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. Fully adhered multi-ply bitumen-based roof membrane systems are recommended in most cases.

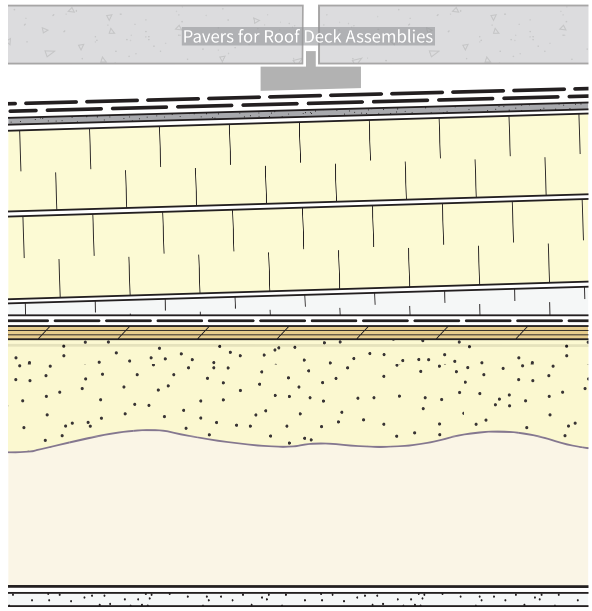


Figure 3-6 Split-Insulated Exposed Membrane Flat Roof

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, polyisocyanurate (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 taper 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.

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**

**Table assumes R-4/inch cavity insulation in 7.25" deep dimensional lumber joists at 16" o.c.*

Vapour Control

The vapour retarder is the self-adhered membrane on the roof sheathing. The split-ratio of insulation should 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.

Design Considerations

An EPS taper package installed with roof insulation (as shown) is often the simplest way to achieve the 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 Detailing at Roof Deck Transitions on page 33 .

Roofing Support & Fasteners for Exterior Insulation

This section provides guidance for the design and construction of roofing attachment that incorporates long screws through strapping and exterior insulation. As discussed in VR-2 | Exterior-Insulated Vaulted Roof on page 12, continuous exterior insulation is one way to efficiently insulate a vaulted roof assembly following building science best practices. The associated roofing attachment and detailing may be new for many designers and builders. In a conventional wood-frame sloped roof assembly, roof sheathing is attached directly to the roof structure, and roofing materials are attached to the sheathing. In an exterior-insulated sloped roof, the addition of exterior insulation and the cross-strapping requires a modified attachment approach.

The guidance provided in this section is for reference only and is not intended to replace project-specific design by a registered professional. Retain consultants with appropriate engineering qualifications to design the roofing attachment system for exterior-insulated vaulted roofs.

Structural Considerations

Typical exterior-insulated vaulted roof assemblies use vertically oriented strapping on the exterior insulation, fastened with long screws through the insulation and into the roof structure, including the inner sheathing and framing. Horizontal cross-strapping is then attached with separate fasteners through the vertical strapping and is used to support the exterior roof sheathing and roofing materials. The bending resistance from the long screws fastened into the roof structure, coupled with a truss system provided by the fasteners acting in tension, and the insulation supporting the compression loads, provides the primary support for the components in the service load state. Additionally, the friction between the insulation and the strapping provides some resistance, though it is generally not accounted for in the structural design. Insulation that is rigid enough to be used in this manner includes EPS, XPS, and polyisocyanurate rigid foam board, as well as rigid stone wool products in places where the snow load is not significant.

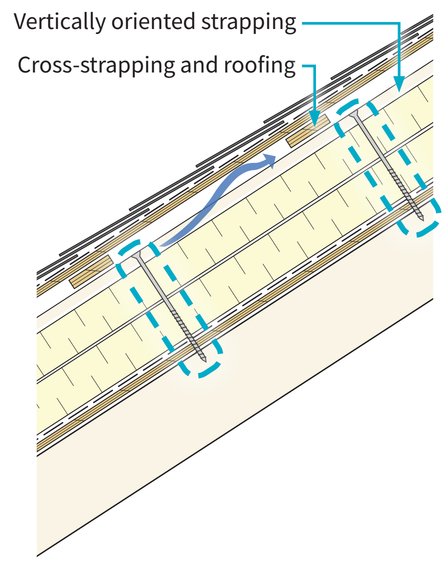


Figure 4-1 Exterior-insulated vaulted roof with long screws through strapping

This roofing attachment system can be used effectively for typical roofing materials including asphalt shingles as well as metal roofing and wood shakes. Heavier-weight roofing materials like concrete tiles typically require additional rigid connections through the insulation (see next page). In many regions throughout BC, the snow load is significantly heavier than the roofing material weight. Therefore, the design of this system is typically governed by the location-specific snow load.

In addition to the snow load, the following factors will also affect the required fastener size and spacing, fastener embedment into structure, and strapping width and thickness:

- roof slope
- roofing material
- joist spacing
- inner sheathing type and thickness
- seismic and wind load forces
- exterior insulation type and thickness
- point loads requiring additional structure
- solar panels, solar water heaters, snow guards, etc.
- access components like roof anchors

Metal panel roofing may be installed without wood cross-strapping. Instead, long screws with bearing plates or dedicated structural clips would be used to retain the exterior insulation boards. In this case, the roofing underlayment is installed directly over the exterior insulation, a drainage/ventilation mat is installed over the underlayment, and the metal roofing is fastened into the insulation clips/plates. This assembly configuration is not discussed in this section.

Strapping

In general, the most appropriate strapping material for this application will be 3/4" (19 mm) plywood strapping ripped to width. After the vertical strapping is installed, more fasteners are installed into it to secure the cross-strapping and exterior roof sheathing, so robust strapping is needed to reduce the risk of splitting the wood. Pre-drilling holes for the long screws is recommended to further reduce the risk of splitting. The required strapping thickness and width for structural purposes is a function of the structural considerations outlined in this section.

Screws

Galvanized or coated hardened carbon steel long screws are typically used to attach the strapping over the insulation because they will be indirectly exposed to the exterior environment in service when used with a vented cross-strapping space. Screws need to be protected from corrosion to ensure long-term durability, so coated screws with salt-spray test ratings (per ASTM B117) of at least 1000 hours are most appropriate. This application may require specialty heavy-duty construction screws designed to accommodate the potentially large torque expected as they are installed through thick layers of insulation and into the roof structure.

Compression & Deflection

In many parts of BC the snow load is many times the weight of the roofing materials including the sheathing and strapping. As a result, there is a significant potential gravity load on the roof assembly that must transfer through the strapping and exterior insulation down to the inner roof sheathing (see schematic illustration on the right). Therefore, the insulation compression strength must be sufficient to prevent the strapping from over-compressing into the insulation. Over-compression can cause the long screws to lose tension and lead to excessive deflection of the strapping and roofing.

In general, in higher snow load environments, higher compression strength rigid insulation like XPS and polyisocyanurate are more appropriate as exterior roof insulation fastened with vertical straps on a sloped roof. Rigid mineral wool is typically not appropriate due to the risk of over-compression and long-term deformation of the straps. However, proprietary clips, compression blocks, or tightly-spaced strapping can be used with rigid mineral wool to reduce the risk of over-compression.

Metal roof assemblies without cross-strapping are generally less prone to this risk since the snow load is distributed more evenly across the insulation.

Regardless, some amount of roofing deflection should be expected and accommodated in the design and construction of exterior-insulated vaulted roofs. This includes avoiding overly taught roof underlayment that can tear across sheathing joints, and using robust flashing detailing with large overlaps.

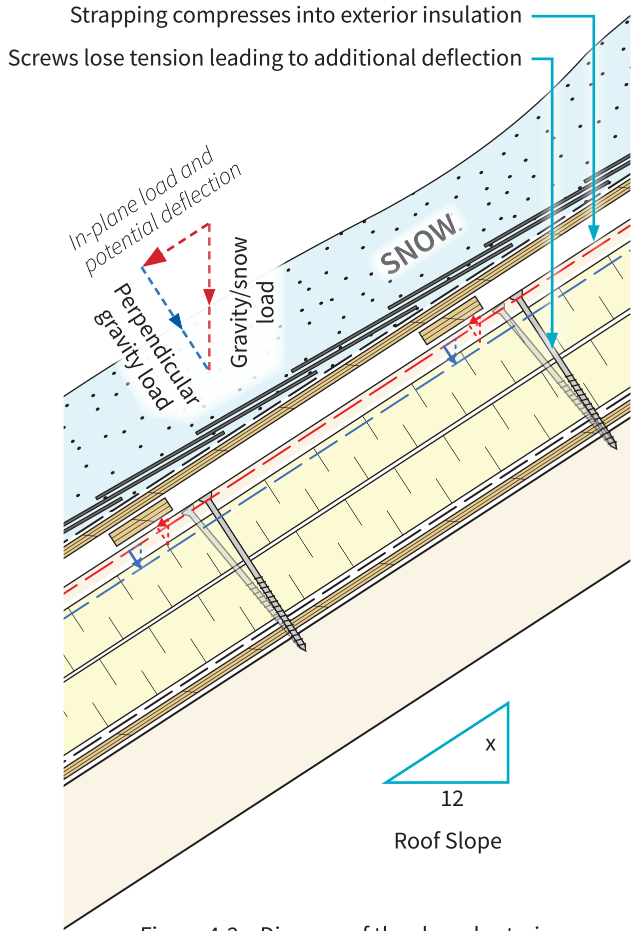


Figure 4-2 Diagram of the sloped exterior insulation design factors

Summary of Guidelines for Structural Components in Exterior-Insulated Vaulted Roofs

The following points are provided as basic design guidelines and assembly considerations for exterior-insulated vaulted roof assemblies with 6"–12" of exterior insulation. These can serve as a starting point for project-specific assembly selection and structural design. This information is for reference only and is not intended to replace project-specific roofing attachment system design by a qualified engineer.

- Typical vertical strapping size: 3" x 3/4" (76 mm x 19 mm) plywood straps or 2x4 (38 mm x 89 mm) dimension lumber.
- Typical vertical strapping spacing: 16” (400 mm) on centre or based on joist spacing.
- Recommended minimum screw embedment: 1” into roof joists or through 3/4” inner sheathing, fastened down with an impact driver to sink the screw head tight against or countersunk into the strapping.
- Typical vertical screw spacing: between 24” and 12” depending on roof slope, insulation thickness, and snow load.
- Minimum fastener length is determined by: insulation thickness + strapping thickness + minimum embedment.
- Typical screw diameter: between 1/4” (6 mm) and 3/8” (10 mm) are typically appropriate, though thicker insulation may require larger diameter screws.
- Roofing material type and weight including straps: maximum 5 lbs/ft² (24 kg/m²), typical for asphalt/laminated shingles on 5/8” sheathing.

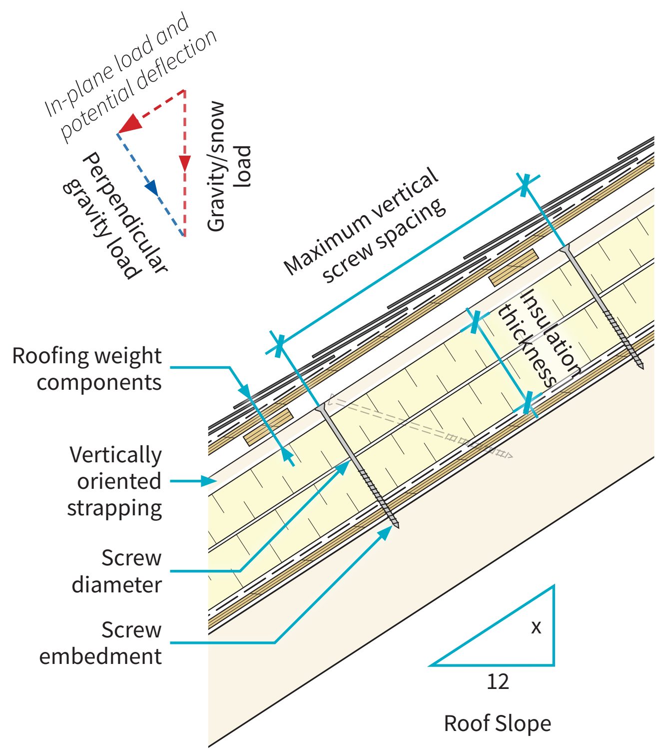


Figure 4-3 Sloped exterior insulation component diagram

Other Assembly Considerations:

- Sufficiently rigid exterior insulation must be used to resist the expected snow load compression.
- Insulation boards should be installed in at least two layers with joints offset in both directions.
- Snow loads are calculated based on the values listed as “Ss” per BCBC Table C-2 and per code-required design factors including wind drift and rain/snow melt.
- Installing additional long screws at an angle (see above graphic) can potentially reduce the risk of deflection since the screws can stay in tension under gravity load/compression compared to perpendicular screws.

Other Insulation Attachment and Roofing Support Options

Where long screws and strapping alone are not suitable, other vaulted roof insulation attachment and roofing support systems can be used. These include proprietary thermally efficient spacer and clip systems, and continuous wood framing through the exterior insulation down to the inner sheathing layer. These approaches can be used to support heavier loads, since they transfer loads directly between the roofing layer down to the roof structure without affecting the insulation layer or relying on screw tension.

Application of Spray Foam in Unvented Roofs

Closed-cell spray foam typically 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 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 items are still worth considering for conventionally vented and top-side vented roofs.

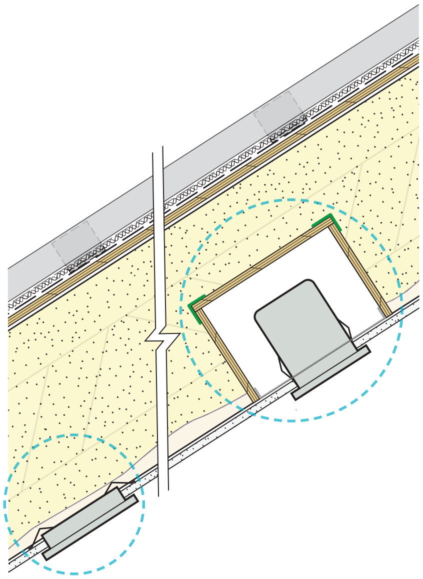


Figure 5-1 Low-profile puck lights or airtight boxes should be used to avoid direct contact with spray foam

Air Barrier & Vapour Retarder Installation

Limiting interior air and vapour movement into the unvented spray foam roof is important to achieving a 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 to 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 layer 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. Note that 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.

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. Due to spray foam's susceptibility to high temperatures, a 3" clearance from heat emitting devices (i.e., pot lights) is required by 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 often not detectable visually from the interior, without the use of exploratory openings at the ceiling. Exterior review may be the only way to detect potential issues, or specialty inspection tools like a moisture meter or thermal camera may be needed. Roof replacement should be planned for as soon as the lifespan of the roofing system is reached. Note that repair 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 non-permeable at 2" thick and serves as a vapour barrier.
- 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 enclosed void spaces.
- 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 Venting Strategies: BCBC - Article 9.19.1.1 & A-9.19.1.1 (1)

The code does not prescribe which roof assemblies require venting. The language is intended to allow the designer to consider whether an assembly is sufficiently water, air, and vapour tight, to minimize the need for venting. 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 venting 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.

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.

Detailing at Roof Deck Transitions

All flat roof assembly types can be used for roofs that allow regular access and foot traffic (i.e., 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 eight inches of the horizontal roof deck surface 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 into the door sill. The roof deck surface must be aligned to allow for both the door sill step and the deck sloping away from the door. This may require the roof deck framing be offset lower than the adjacent floor framing. Accessibility requirements must also be considered in the design of door sills.

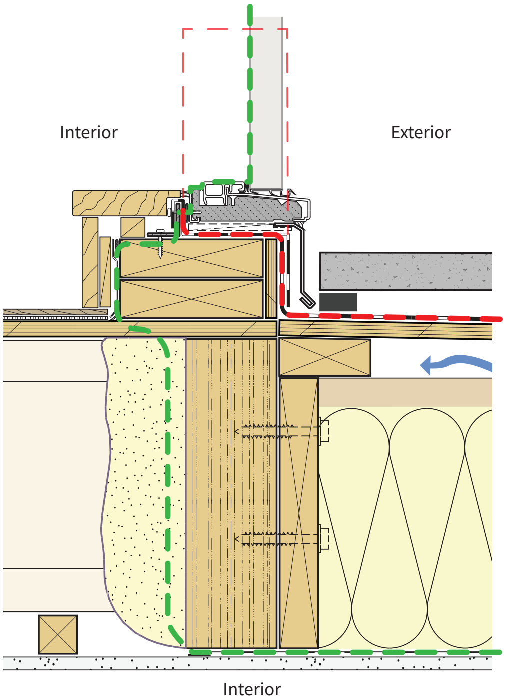


Figure 6-1 Vented roof deck (flat roof FR-3) with offset framing, roof membrane from the deck up into the door sill (red dash), and interior air barrier (green dash).

Deck Membrane

All roof decks must be designed and constructed as standard flat roofs. Torch-applied multi-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 (flat roof "FR-3" and "FR-5") must include adequate venting from the perimeter of the roof deck over the insulation. This can be difficult if the deck is enclosed with walls on all sides. Exterior air barrier assemblies that do not require venting (flat roofs "FR-1", "FR-2 and "FR-6") may be simpler, but the structural connection must account for the height of the exterior insulation and door access.

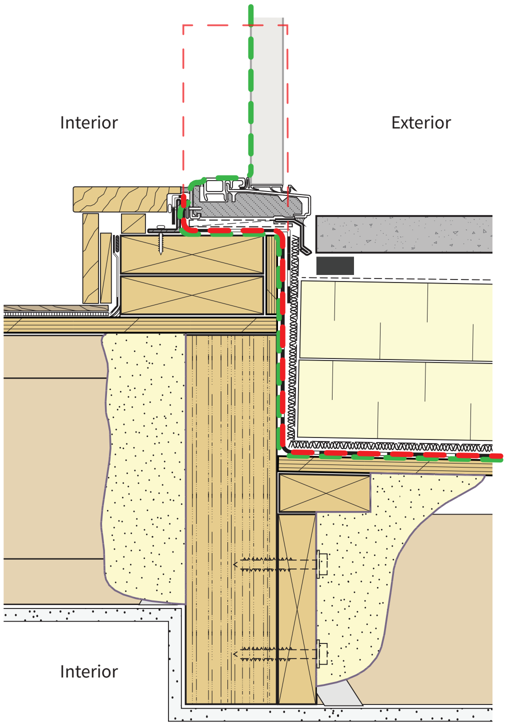


Figure 6-2 Inverted roof deck (flat roof FR-2) with offset framing, roof membrane from the deck up into the door sill (red dash), and exterior air barrier (green dash).

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. As with most interior air barrier transitions, this can be a difficult detail to properly sequence. Roof assemblies with exterior air barriers are generally more straightforward to tie into the surrounding walls.

Roof assemblies with exterior air barriers at the primary roof sheathing above the structure but separate from the roofing membrane (flat roofs "FR-1", "FR-5", and "FR-6"), allow detailing and air barrier tie-in around the perimeter of the roof assembly before the roofing membrane is installed, which can further simplify the process. As shown in the illustrations on the right, an exterior air barrier can still include joist insulation, with venting as shown (flat roof "FR-5") or additional exterior insulation (flat roofs "FR-6"), to reduce the amount of exterior insulation, and therefore, potential framing offset needed.

For roof assemblies where the roofing membrane is also serving as the air barrier, the air barrier transition must include the roofing products (see Figure 6-2).

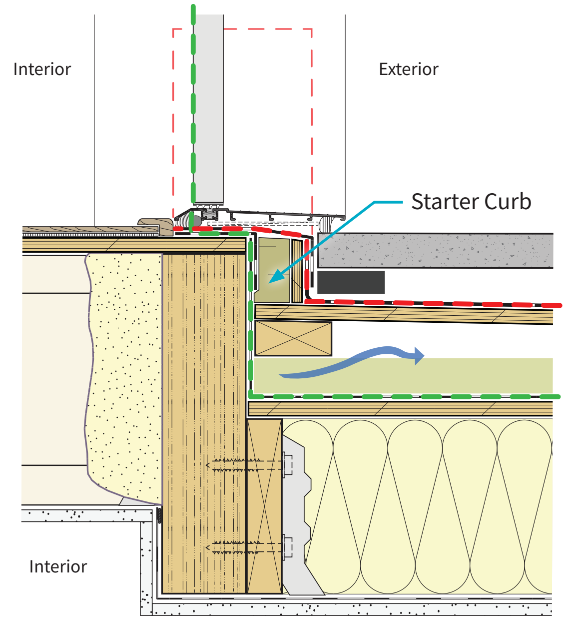


Figure 6-3 Top-side vented roof deck (flat roof FR-5) with a continuous exterior air barrier from the deck membrane through the sill membrane behind the starter curb, through sealant to the door assembly (green dashed line).

Renewable Details

As with all building enclosure assemblies, components and materials that have shorter lifespan and maintenance/replacement intervals should be positioned so that they can be accessed without significantly disrupting other components that do not require replacement. The roof deck assembly is an excellent example of this situation: the roof membrane itself may have a full replacement interval of 20 to 30 years, but the surrounding air barrier and cladding components could have much longer service intervals. In fact, an exterior air barrier could be designed and installed to last the life of the building such that it does not ever need to be fully replaced. If service work on shorter-interval roofing systems causes damage to the otherwise continuous air barrier, the integrity of the building enclosure may be compromised, which can lead to long-term durability risk.

Therefore, the detailing should include components that make service work easier and reduce the risk of damage to the air barrier. As shown in the illustration on the right, the roof deck starter curb is an excellent renewable detail that separates the roofing membrane from the roof and wall air barrier materials, and includes easily removable components that reduce the risk of damage to the air barrier during replacement work. This starter curb concept applies to many roof-to-wall interfaces. For more example details of the roof deck starter curb, refer to BC Housing's *Exterior Air Barrier Reference Sheet—Sealed Sheathing Membrane.*

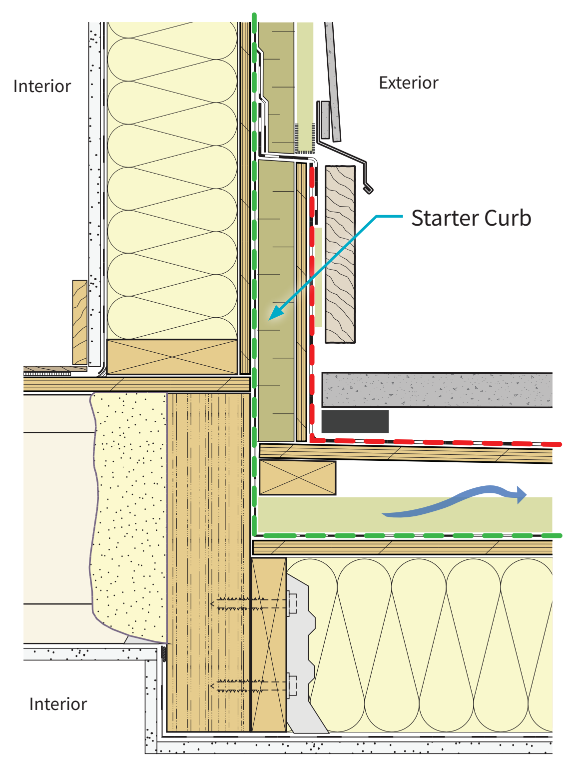


Figure 6-4 Top-side vented roof deck (flat roof FR-5) with a starter curb at the base-of-wall to allow roof service work without affecting the continuity of the air barrier (green dashed line).

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 airtightness.

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 more manageable, because it does not interface with interior elements like framing, penetrations or finishes. However, the exterior air barrier still must interface with interruptions at the outside of the building like plumbing stacks and structural components. The design and detailing must account for these. In either approach, it is important that some airtightness be provided at the interior side of the insulation.

Ceiling Penetrations

Common ceiling penetrations such as recessed 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.

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 damaging 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.

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. A third wall top plate may be needed to offset the lower ceiling height.

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 11 | Additional Resources on page 42).

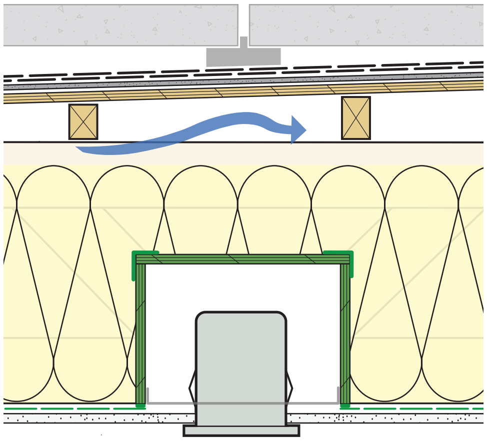


Figure 7-1 Airtight plywood and high performance tape service box sealed to ceiling polyethylene.

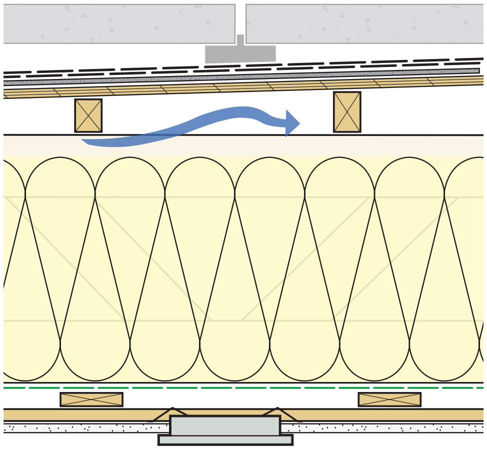


Figure 7-2 A ceiling service cavity provides space to run services without interrupting the air barrier.

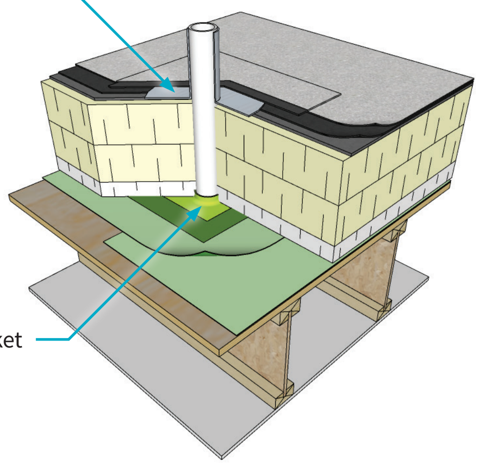


Figure 7-3 Exterior Sheathing Membrane Approach

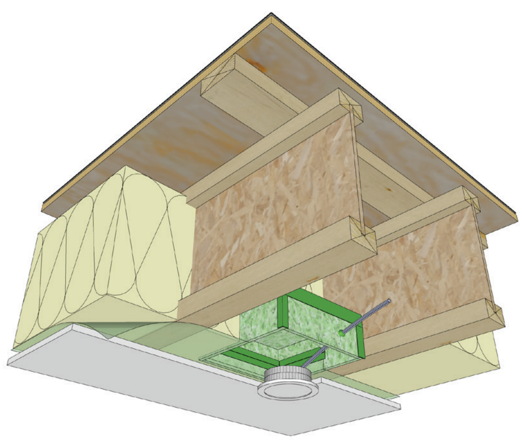


Figure 7-4 Sealed Interior Polyethylene Approach

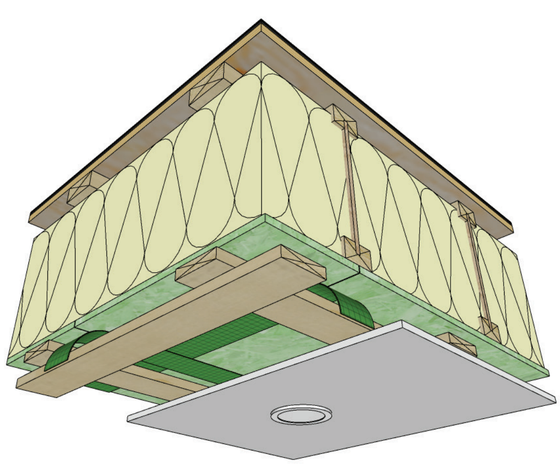


Figure 7-5 Sealed Interior Sheathing Approach (with Service Cavity)

Air Barrier Systems

Exterior Sheathing Membrane Approach

This approach uses a fully adhered membrane as the primary air barrier element. Self-adhered 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

This approach uses polyethylene sheets 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)

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.

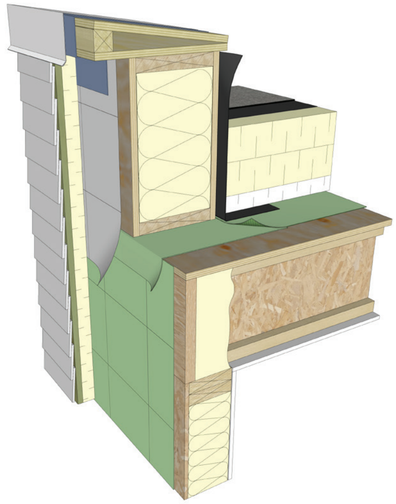


Figure 7-6 Parapet Pre-Strip

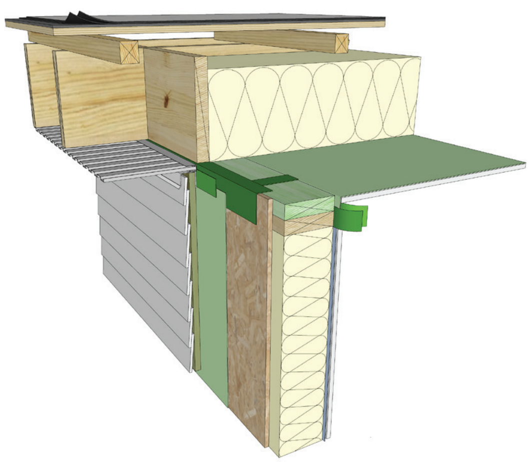


Figure 7-7 Taped Top Plate

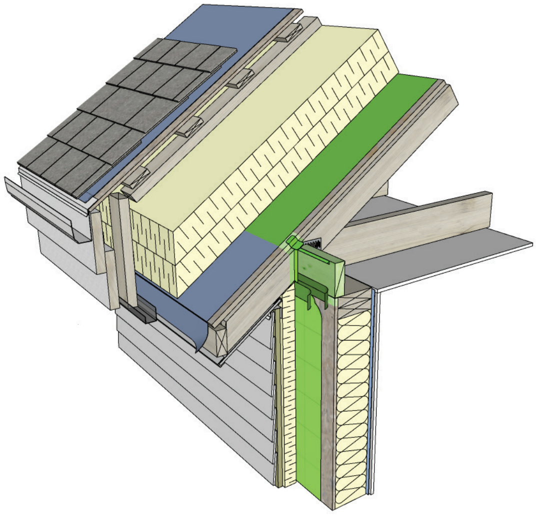


Figure 7-8 Sealed Blocking and Sheathing

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 through a framed parapet 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 parapet air barrier transition at the flat roof-to-wall detail.

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, including around interior walls. 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 compared to alternatives like polyethylene strips between top plates. The tape used in this method should be high-performance sheathing tape.

Sealed Perimeter Blocking and Sheathing

The air barrier transition between sheathing membrane on the inner roof sheathing (see VR-2) and the wall membrane is achieved with sealed perimeter blocking and butyl double-sided tape. High performance sheathing tape and perimeter sealant is used to seal blocking, and butyl tape is placed over each rafter/joist to form a continuous air barrier between the inner roof sheathing and the blocking below. This detail requires careful sealant work and appropriate double-sided butyl tape over each rafter/joist beneath the inner roof sheathing. This double-sided tape is the only element installed during framing. The rest can be completed later when other membrane work is underway. This approach allows standard truss/joist arrangements and framing practices otherwise.

Top-Side Vented Vaulted Spray Foam Roof

This assembly is designed with a 2.5" roof venting space between the roofing and the inner roof sheathing. While this roof is similar to VR-3 | Joist-Insulated Unvented Spray Foam Vaulted Roof on page 14, this deeper vent space is intended to comply with prescriptive code requirements for roof venting, while still allowing a fully insulated joist cavity. This assembly is well-suited to vaulted spray foam roofs where venting may not otherwise be possible. This approach can be used with standard roof coverings like conventional shingles or with metal roofing. It is important that the sheathing membrane used beneath the venting space be vapour permeable, to allow potential drying of the roof assembly.

This assembly may also benefit from using the sheathing membrane as an exterior air barrier on the inner roof sheathing, instead of relying on an interior air barrier (see 7 | Airtightness on page 35).

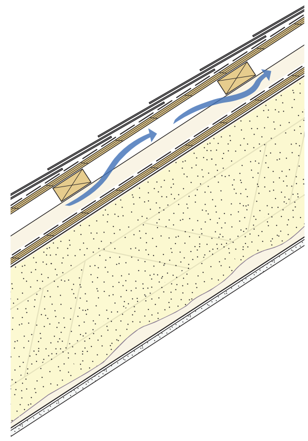


Figure 7-9   Top-Side Vented Vaulted Spray Foam Roof

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. Joints should be insulated and sealed following the manufacturer's recommendations.

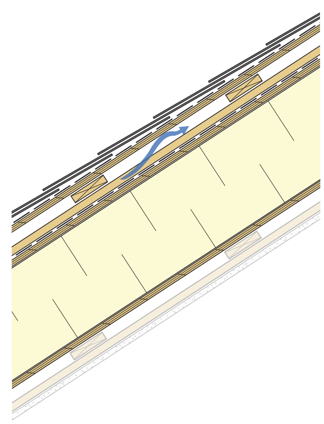


Figure 7-10 SIP Vaulted Roof

9 | Maintenance & Inspections

Regular inspection and maintenance are 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.

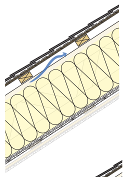
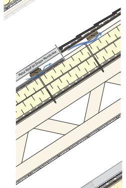
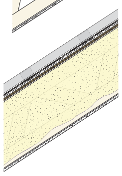
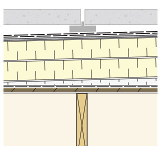
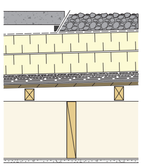
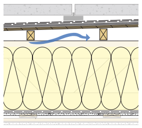
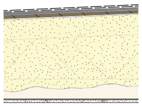
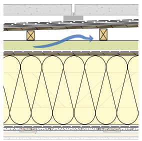
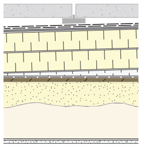
Life expectancies of roofs can range from 10 years to over 30 years, depending on the roof design, exposure, construction, and materials used. Roofs should be replaced before the likelihood of significant failure gets too high, to avoid potentially costly damage from water leakage.

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's 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.

Detailed discussions of each assembly, including thermal performance values, have been provided throughout the guide. This section provides a summary of the key considerations and the minimum insulation levels required for each assembly to achieve approximately R-30 effective, which is considered moderate to high-performance insulation value.

				Min. Insulation Levels to Achieve R-30 Effective	Key Considerations
Vaulted	Vented		VR-1	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	Vented		VR-2	8" of R-4/inch of rigid insulation 6" of R-5/inch of rigid insulation	Good roof detailing, water tightness of the roof underlayment, and the continuity of the air barrier at the primary inner roof sheathing are critical to the performance of the assembly.
Vaulted	Unvented		VR-3	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		FR-1	7" of R-4/inch rigid insulation 6" of R-5/inch rigid insulation 5" of R-5.6/inch rigid insulation	An EPS taper package installed with the roof insulation is often the simplest way to achieve required sloping. Multiple insulation layers should be offset in both directions to provide a continuous thermal insulation layer.
Flat	Inverted		FR-2	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		FR-3	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		FR-4	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	Vented		FR-5	2x12 joists with 10" of R-3.4/inch batt insulation 9.5" I-joists with 8.5" of R-4/inch batt insulation	Sheathing surface treatment to inhibit mould growth may be prudent in these roof assemblies to reduce the elevated risk of surface mould growth on the exterior roof sheathing, as a result of moisture in venting air.
Flat	Split-Insulated		FR-6	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 two-thirds of the nominal R-value on the exterior side, and the remaining one-third of the insulation in the roof joist cavity. Otherwise, a hygrothermal analysis should be completed.

11 | Additional Resources

Design Guides

- *BC Energy Step Code Design Guide and* BC Energy Step Code Builders 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 FPInnovations, BC Housing, and the Canadian Wood Council
  (Available at www.fpinnovations.ca)
- *Building Envelope Guide for Houses - Part 9 Residential Construction, 2020 Second Edition* published by BC Housing
  (Available at www.bchousing.org)
- *Building Enclosure Design Guide* - Second Edition 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)
- Exterior Air Barrier Reference Sheet - Sealed Sheathing Membrane published by BC Housing
  (Available at www.bchousing.org)
- *Roof Maintenance Guide* and *Roofing Practices Manual* by Roofing Contractors Association of BC
  (Available at www.rcabc.org/technical/)
- *Standard for Architectural Sheet Metal (ASM) Systems* by Roofing Contractors Association of BC
  (Available at www.rcabc.org/technical/)

Thermal Calculations

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

Building Codes

- *Vancouver Building By-law (VBBL) 2019* published by the King's Printer for British Columbia
- *British Columbia Building Code (BCBC) 2024* published by the King's Printer for British Columbia

NOTES

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