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M-25608.000
ACC - Alberta Unvented Roofs | Evaluation Report

DATE March 4, 2022

REGARDING **Engineered Solution for Part 9 Unvented Roof Assemblies in Alberta**

Dear Mr. Wieroniey,

As requested by the American Chemistry Council (ACC), RDH Building Science Inc. (RDH) is pleased to provide you with this engineered solution for the design and construction of unvented spray foam roof systems within in Part 9, Housing and Small Buildings, of the National Building Code – 2019 Alberta Edition (NBC) which is the governing building code within the province of Alberta, Canada.

It is our understanding that the Province of Alberta is considering allowing unvented spray foam roof assemblies in the construction of Part 9 buildings. This report supports that decision with a review of existing literature, summary of moisture physics, some typical schematic details, as well as limitations and requirements of these assemblies. There are many unvented spray foam roofs already being constructed in Part 9 buildings in the province of Alberta, but within the current building code provisions each project must be approved individually.

This report explains the performance of wood framed roofs with 2 pound per cubic foot (pcf) closed-cell spray polyurethane foam, referred to in this report as medium density spray polyurethane foam (MDSPF) which conforms to CAN/ULC S705.1, the standard for the spray foam specification within the NBC. This report also includes discussion of wood framed roofs with 0.5 pcf open-cell spray polyurethane foam, referred to in this report as light density spray polyurethane foam (LDSPF) which conforms to CAN/ULC S712.1, the standard for the spray foam specification within the NBC. This report assumes that all spray foam is installed as per the manufacturer's instructions, and in compliance with the installation guidelines of CAN/ULC S712.2 for MDSPF, and CAN/ULC S705.2 for LDSPF. It is further assumed that all rainwater management details are designed and constructed correctly.

Construction under Part 5 construction already allows unvented spray foam roof assemblies since all Part 5 buildings require design and engineering by registered professionals

This report is limited to the province of Alberta and the climate zones it includes as shown in Figure 1.

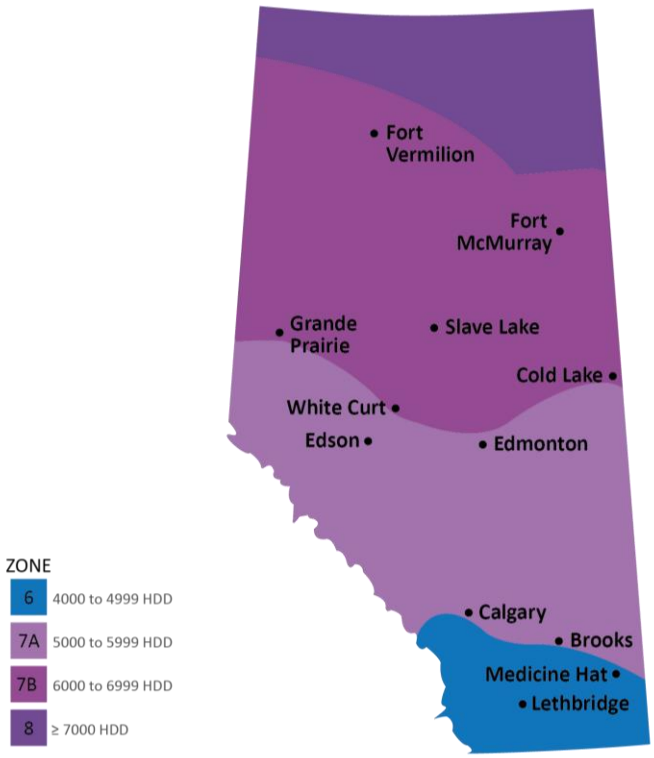

Figure 1 : Canadian climate zones of Alberta (NBC 2015)

1 Background

In preparation of this report, a combination of codes, peer reviewed scientific conference papers, and industry documents have been reviewed regarding the use of unvented spray foam roof assemblies. These documents are listed here;

- National Building Code of Canada – Alberta Edition. 2019
- United States International Residential Code (IRC). 2018
- Smegal, J. et al. State of the Art Review of Unvented Sloped Wood-framed roofs in cold climates. 15th Canadian Conference on Building Science and Technology. Paper 106. 2017
- Smegal, Jonathan and John Straube. 2014. "Ventilation and Vapor Control for PSF-Insulated Cathedral Ceilings." Report by Building Science Consulting Inc. in coordination with the University of Waterloo Building Engineering Group BEGHut for the Canadian Urethane Foam Contractors Canadian Spray Foam Guide 2013
- Schumacher (2007). BSD-149 Unvented Roof Assemblies for All Climates. Building Science Consulting. Westford, MA.
- Straube, J., Smegal, J., and Smith, J. 2010. Moisture-safe unvented wood roof systems. *In* Proceedings of Building Enclosure Science & Technology, Portland, Or, 12-14 April 2010. National Institute of Building Sciences, Washington, DC.

1.1 Building Code Review

In Canada, a vented roof assembly is the only roof assembly currently prescriptively allowed in Part 9 buildings. Engineering reports that can demonstrate that ventilation is unnecessary are considered by the building code official as per Sentence 9.19.1.1 (1) of the NBC.

> *"Except where it can be shown to be unnecessary, where insulation is installed between a ceiling and the underside of the roof sheathing, a space shall be provided between the insulation and the sheathing, and vents shall be installed to permit the transfer of moisture from the space to the exterior.*

The justification for this sentence in the code can be found in the NBC Appendix in A-9.19.1.1.(1):

> *Controlling the flow of moisture by air leakage and vapour diffusion into attic or roof spaces is necessary to limit moisture-induced deterioration. Given that imperfections normally exist in the vapour barriers and air barrier systems, recent research indicates that venting of attic or roof spaces is generally still required. The exception provided in Article 9.19.1.1 recognizes that some specialized ceiling-roof assemblies, such as those used in some factory-built buildings, have, over time, demonstrated that their construction is sufficiently tight to prevent excessive moisture accumulation. In these cases, ventilation would not be required.*

This appendix note explains that the reason attic ventilation is required is to manage the moisture related to air leakage and vapour diffusion from the interior moving towards the cold roof sheathing and accumulating, potentially causing damage to the wood substrates. However, if an air impermeable insulation combined with the required vapour control is installed directly to the underside of the roof deck, and there are no parallel air leakage paths, then there is limited risk of air leakage or substantial vapour flow, and ventilation below the roof deck is not necessary to provide control within the roof assembly.

The International Residential Code (IRC 2018) in the United States, has recognized that there are assemblies that can be constructed prescriptively as unvented roof assemblies. Section 806.5 (5.1) explains the prescriptive criteria for an unvented roof assembly. In the summary below, there are three conditions that are allowed by the code:

1. Sufficient rigid board or sheet insulation shall be installed directly above the structural roof sheathing. This type of construction is typically associated with commercial buildings where all of the roofing insulation is installed on the exterior of the structure and air control layer and is then covered by the roofing membrane. This is a very safe roof strategy since the structure stays warm preventing moisture accumulation, and the air control layer applied to the structure stops the warm air from getting into the insulation and reaching the colder surfaces.
2. Where spray polyurethane foam insulation is installed, it shall be applied in direct contact with the underside of the structural roof sheathing.
3. When a combination of air impermeable (board foam or SPF) and air permeable (mineral fiber batts) are used in the assembly, then the air impermeable insulation must either be on the exterior of the structure, or directly adhered to the underside of the roof sheathing, and the air permeable insulation must be installed directly to the interior so there are no voids or gaps in the assembly. Most importantly, the R-value ratio between the two types of insulation must ensure that condensation will not occur at the interface between the two.

These stipulations in the IRC allow construction of unvented roof assemblies in any climate zone in the United States which are the same as the Canadian climate zones.

Currently in Alberta, every Part 9 construction project that is specified with an unvented roof assembly, must get a sealed engineering judgement letter for each specific case. Acceptance of the prescriptive use of certain unvented assemblies that are known to be very low risk would make design and construction of these assemblies more time and cost efficient, while providing durable, energy efficient roof systems.

2 Unvented Roof Assemblies

This report addresses three options for unvented roof assemblies in Part 9 construction. The images in this report focus on the sloped portion of the roof assembly, but it is important to remember, that in roof assemblies that have vertical portions, such as gable ends, they will require the same treatment as the sloped roof portions.

1. Unvented Cathedral Ceiling – The thermal control (insulation) is located within the roof framing, and the ceiling plane follows the plane of the roof (Figure 2).
2. Unvented Cathedralized Attic – The thermal control (insulation) is within the roof deck, and the ceiling plane is horizontal leaving an attic space that will require some space conditioning. (Figure 3)
3. Unvented Low-slope (flat) roofs – This is the most commonly constructed unvented roof assembly, although more traditionally it is used in commercial construction. The thermal control and ceiling plane are both essentially horizontal with only minimal (less than 25% but greater than 2%) slope so that water will drain from the roof membrane. This slope is usually a result of sloped insulation on a horizontal structure, but in some cases, the structure itself is sloped for drainage.

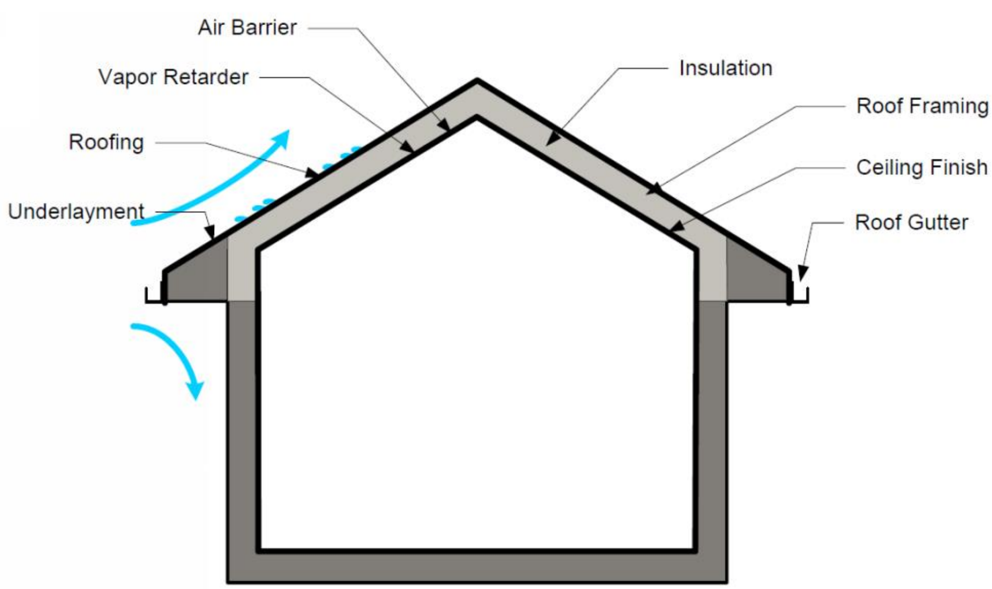

Figure 2 : Unvented Cathedral Ceiling (image credit Schumacher[1])

[1] Schumacher, C. Hygrothermal Performance of Insulated, Sloped, Wood-Framed Roof Assemblies, Masters Thesis, University of Waterloo, Waterloo, Canada. 2008

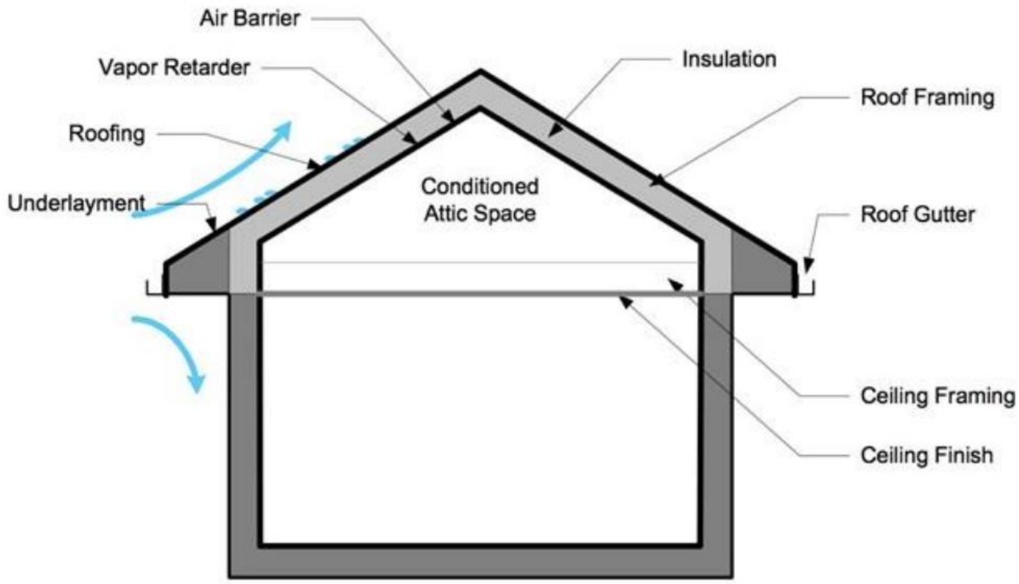

Figure 3 : Unvented cathedralized attic (image credit Schumacher[2])

There are several architectural, practical and durability related advantages to unvented roof assemblies.

- In many roof designs the geometries are complex making it very difficult to get adequate and effective ventilation of a ventilated roof assembly, potentially resulting in moisture accumulation.
- Unvented roof assemblies do not allow the ingress of blowing snow, rain, or burning ashes in wildfire areas. In many locations with high forest fire risk, ventilated roof systems are not allowed because of the history of attic fires as a result of embers entering the attic.
- Moving the thermal control layer of the attic to the roof sheathing/framing level allows for easier installation of HVAC into the attic, and because the HVAC is inside the thermal enclosure, there is less concern for leaky ductwork, and challenging extreme temperature conditions for the equipment and any condensate or drain lines.
- There are typically fewer penetrations at the roof deck compared to the ceiling level which often includes lights, speakers, and other wiring that results in air leakage through the air barrier.
- Cathedralized attics allow more useable space for the occupants either as conditioned storage space or bonus rooms.
- Unvented cathedral ceilings provide a greater interior volume which is often architecturally desirable to the homeowners.

Table 1 shows a summary of the effective thermal resistance requirements for unvented roofs of the 2019 National Building Code of Canada based on Tables 9.36.2.6 A and B which account for buildings with and without heat-recovery ventilators. The effective R-

[2] Schumacher, C. Hygrothermal Performance of Insulated, Sloped, Wood-Framed Roof Assemblies, Masters Thesis, University of Waterloo, Waterloo, Canada. 2008

value accounts for thermal bridging of the framing using either the isothermal planes or parallel-path calculation methods to determine the effective R-value.

TABLE 1 : REQUIRED EFFECTIVE* THERMAL CONTROL IN UNVENTED ROOF ASSEMBLIES (NBC 2019)		
ZONE (HDD 18)	THERMAL INSULATION R-VALUE [$FT^2 \cdot °F \cdot H/BTU$]	THERMAL INSULATION RSI VALUE [$M^2 \cdot K/W$]
Zone 6 (4000 to 4999)	26.5	4.67
Zone 7A (5000-5999)	28.5	5.02
Zone 7B (6000 to 6999)	28.5	5.02
Zone 8 (≥7000)	28.5	5.02

* Effective thermal resistance calculations will account for closely spaced, repetitive structural members such as studs and joists. (See NBC Note A-9.36.2.4.(1) for calculation equations)

Following the example in NBC A-9.36.2.4.(1), Table 2 below shows the assembly effective R-value calculation for a cathedral ceiling with 2x10 lumber rafters 406mm (16 in) o.c. Based on the NBC Table A-9.36.2.4.(1)-A, this equates to assumed 13% framing, and 87% insulated cavity. The RSI value chosen for the MDSPF was 0.04 RSI/mm (R5.6/in) based on the published LTTR test data of some common MDSPF. However, when these calculations are completed for the submittal of a specific project, the advertised RSI value of the specific foam being installed must be used in the calculation. Table 2 shows that a depth of 7" (178mm) of MDSPF between 2x10 rafters will achieve a total effective RSI of 5.3, or R-value of 30. This means that based on the assumptions used in the calculation for the analysis, a minimum of 7" of MDSPF would be required in this assembly to achieve the minimum thermal effective R-value for Zones 7A, 7B, and 8 currently required in Table 1 above.

TABLE 2 : CALCULATION OF EFFECTIVE R-VALUE IN A CATHEDRAL CEILING		
LAYER	T	THERMAL RESISTANCE RSI
Outside air film		0.03
Shingles		0.08
Underlay		-
Framing (2x10 rafters) 16" o.c. (406 mm o.c.)	RSI_F = 1.56 – 13% area[1]	4.55[2]
Insulation – 7" (178mm) MDSPF	RSI_C = 7.12[3] – 87% area[1]	
Air space ~50mm		0.16
Gypsum (12.7 mm)		0.08
Interior air film		0.11
Total Assembly Effective RSI		**5.3**

[1] Framing and Cavity Percentages for Typical Wood-frame Assemblies NBC Table A-9.36.2.4.(1)-A

[2] RSI parallel using the assumed material R-values and framing factors

[3] Use the listed RSI data for actual MDSPF product being installed when submitting this calculation for approval of AHJ.

3 Building Science of Unvented Roofs

The main concern with all aspects of the enclosure, but most importantly roofs in cold climates, is moisture accumulation on the interior surface of the wood-based roof sheathing as a result of outward air leakage or vapour diffusion of interior air. Air leakage moves 1-2 orders of magnitude more moisture in a given timeframe than vapour diffusion, so it is less common that vapour diffusion causes significant condensation and moisture issues.

One key variable related to the moisture durability risk of any enclosure assembly (wall or roof) of a building is the interior relative humidity level of the interior space in the wintertime when the risk of moisture accumulation in the enclosure is the greatest in a cold climate. Interior relative humidity must be maintained at the recommended level, which in cold climates is 30-35% according to the NBC 2015.

Roofs have a higher risk of condensation than walls, because the exterior surface of the roof assemblies can cool to temperatures lower than the ambient environment as a result of radiative heat transfer with the sky. This means that even if the temperature outside is slightly above freezing (ie. 2-3˚C), frost can develop on the roof assembly in areas that are exposed to the sky on a clear night because the exposed surface temperature of the roof is depressed by radiation to below freezing temperatures. This mechanism creates a situation where the roof sheathing temperature is reduced to and maintained at colder temperatures than the wall sheathing and increases the severity and duration of possible moisture accumulation within the roof sheathing.

There are two strategies for unvented roof assemblies that minimize the risk of moisture accumulation within the roof assembly. These strategies follow the recommendations of the widely accepted United States IRC prescriptive requirements:

> **Option 1:** Install only rigid or semi-rigid insulation on the exterior of the roof structure and provide an air barrier to meet the building code requirement. This will ensure that the temperature of the roof sheathing is approximately the same as the interior space and will not result in elevated relative humidity or moisture accumulation. The exterior insulation also minimizes the thermal bridging effects of the framing in the roof assembly increasing the effective R-value of the roof assembly. This assembly may have an empty cavity space below, or in some cases may have an exposed structural wood deck such as tongue and groove pine, or CLT mass timber. It's important to install an air barrier and vapour retarder at the interior of the insulation to prevent water vapour, both by air leakage and vapour diffusion, into the insulation layers.
>
> Figure 4 and Figure 5 show labelled drawings of both an exterior insulated sloped and flat roof assembly, including the key components and their identified roles in the assembly as recommended for construction.

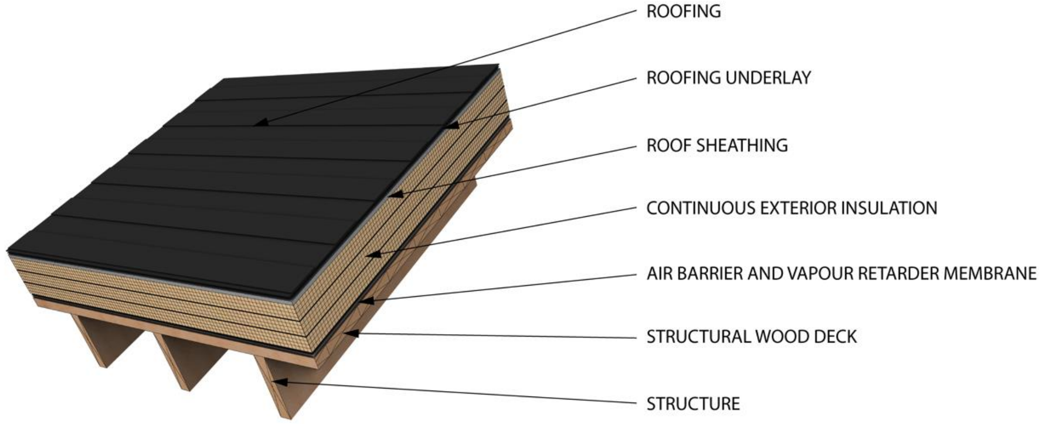

Figure 4 : Exterior insulated sloped roof assembly

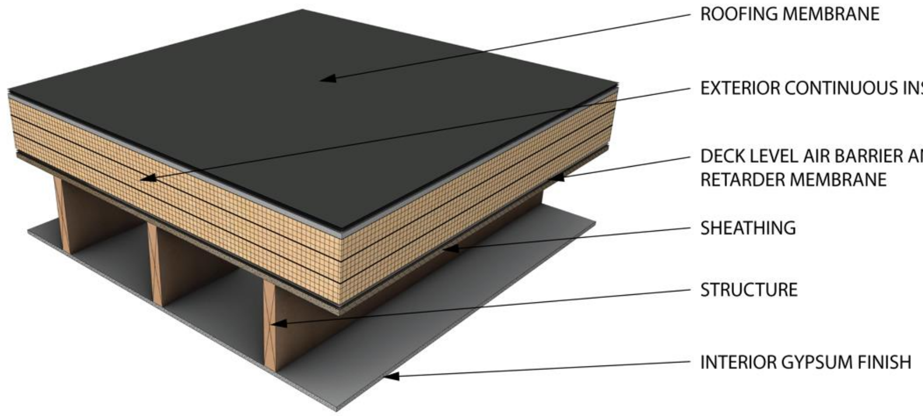

Figure 5 : Exterior insulated low slope (flat roof) assembly

Option 2: Install medium density closed cell spray foam (MDSPF) or light density open cell spray foam (LDSPF) against the underside of the roof deck in sufficient quantity to meet the building code thermal requirements for effective R-value. Both LDSPF and MDSPF meet the air barrier requirement when correctly installed, however only MDSPF is an approved vapour barrier layer at the required installed thicknesses. This means that with MDSPF, interior moisture will not reach the sheathing by either vapour diffusion or air leakage through the field of the spray foam. LDSPF requires additional continuous effective vapour control on the interior of the spray foam in cold climates to meet the building code requirements and to prevent moisture accumulation in the spray foam. Vapour control can be achieved with sheet applied approved vapour barriers (such as 6mil polyethylene), sealed around all penetrations. Smart vapour barriers, that meet the vapour barrier requirements of the code, but allow for higher vapour permeance at elevated relative humidity levels could also be used provided the interior relative humidity is controlled. Vapour barrier paints specifically tested and approved for use on spray foam could also be installed provided the installation recommendations and specifications are followed.

Figure 6 and Figure 7 show labelled drawings of both a sloped and flat roof assembly insulated with spray foam, including the key components and their identified roles in the assembly as recommended for construction.

Installing insulation around the framing does allow thermal bridging of the insulation through the wood structure since the thermal conductivity of wood is greater than insulation. This thermal bridging will decrease the effective R-value of the assembly and therefore greater insulation thickness is required to achieve the required effective R-value. The effective R-value can be calculated, and is required to meet the building code in many jurisdictions. In any assembly with spray foam installed between structural members, care must be taken to ensure the air barrier continuity is maintained between side-by-side or built-up wood components where spray foam can not be installed.

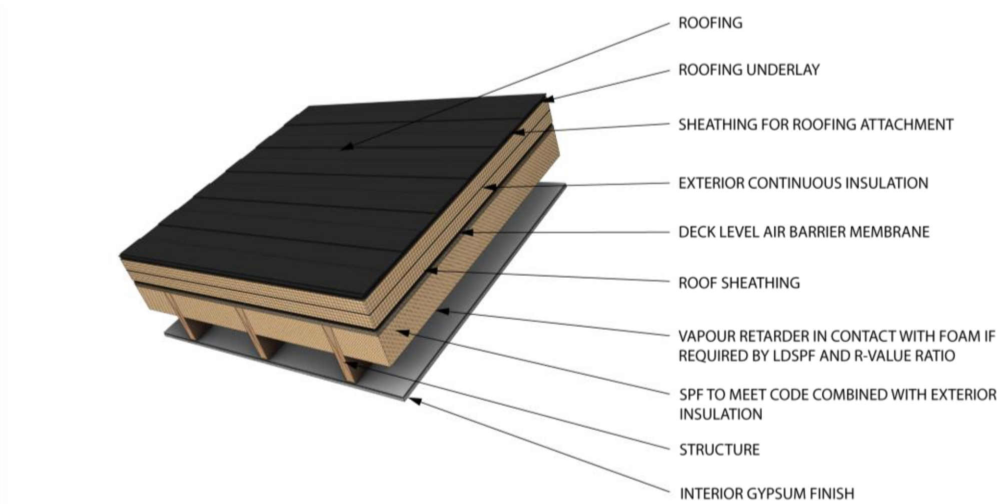

Figure 6 : SPF insulated sloped roof assembly

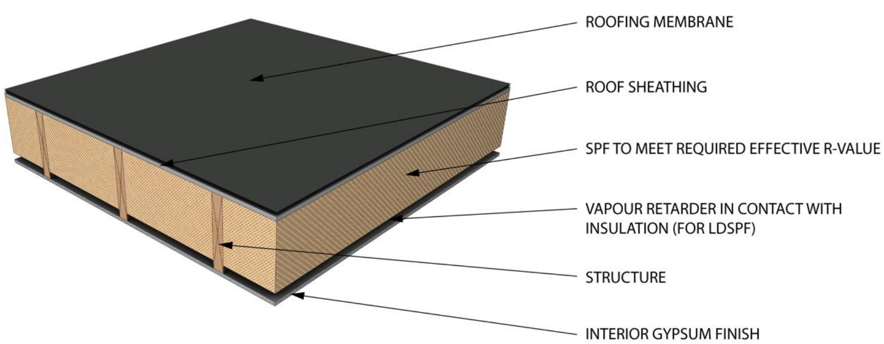

Figure 7 : SPF insulated flat roof

A combination of exterior insulation against the exterior of the sheathing (Option 1), and MDSPF installed directly to the interior of the sheathing (Option 2) with a combined effective R-value sufficient to meet the code, with minimized thermal bridging of the structure through the assembly (Figure 8). Substituting LDSPF for MDSPF may require a vapour Barrier installed on the interior (warm in winter) side of the assembly, depending on the R-value ratio of the exterior board foam to the interior LDSPF. This should be determined on a case-by-case basis.

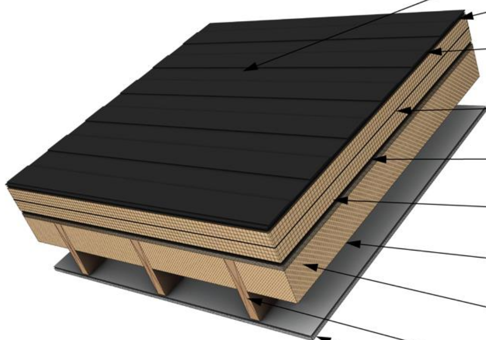

Figure 8 : Roof assembly with exterior insulation and MDSPF

A third strategy combining air and vapour impermeable insulation such as MDSPF or continuous exterior insulation with air permeable insulation such as mineral wool batts or blown in fibrous insulation (Figure 9 and Figure 10) can also work, but appropriate balance in the R-value ratio of the air impermeable insulation to the air permeable insulation needs to be determined such that condensation and moisture accumulation does not occur at the interface of the two insulation types. As mentioned previously, these two insulation layers need to be installed without any gaps, or voids between the insulation layers.

There is general guidance related to the R-value ratios in these hybrid insulation assemblies based on building physics available in the 2021 International Residential Code (IRC) in Table 1202.3 “Insulation for Condensation Control”. An excerpt of the IRC table is shown below in Table 3. The table demonstrates that for any location in Alberta, at least half of the R-value must be air and vapour impermeable insulation to minimize moisture accumulation risks.

TABLE 3 : MINIMUM R-VALUE OF AIR-IMPERMEABLE INSULATION. EXPRESSED AS A PERCENTAGE OF TOTAL R-VALUE (EXCERPT FROM TABLE 1202.3 OF 2021 IRC)

ZONE (HDD 18)	MINIMUM PERCENTAGE REQUIRED OF AIR AND VAPOUR IMPERMEABLE INSULATION FOR CONDENSATION CONTROL
Zone 6 (4000 to 4999)	50%
Zone 7A (5000-5999)	60%
Zone 7B (6000 to 6999)	60%
Zone 8 (≥7000)	70%

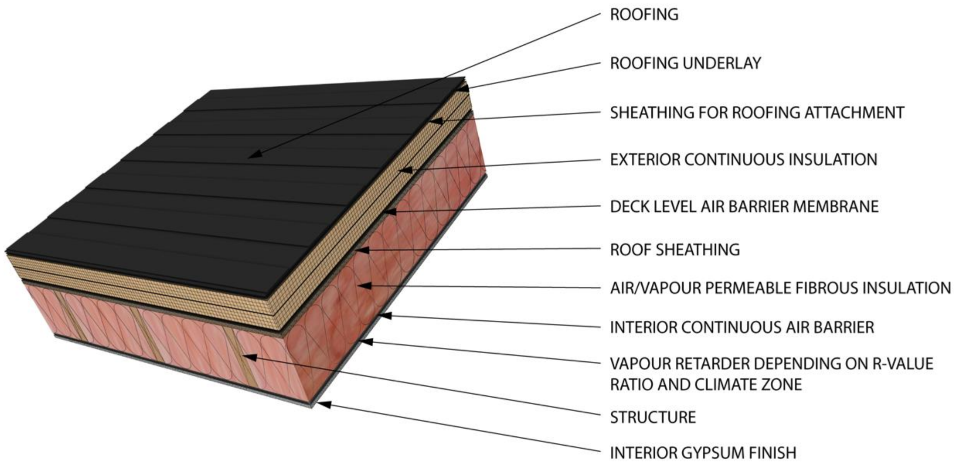

Figure 9 : Hybrid roof assembly combination of air impermeable exterior insulation and air/vapour permeable insulation within the framing.

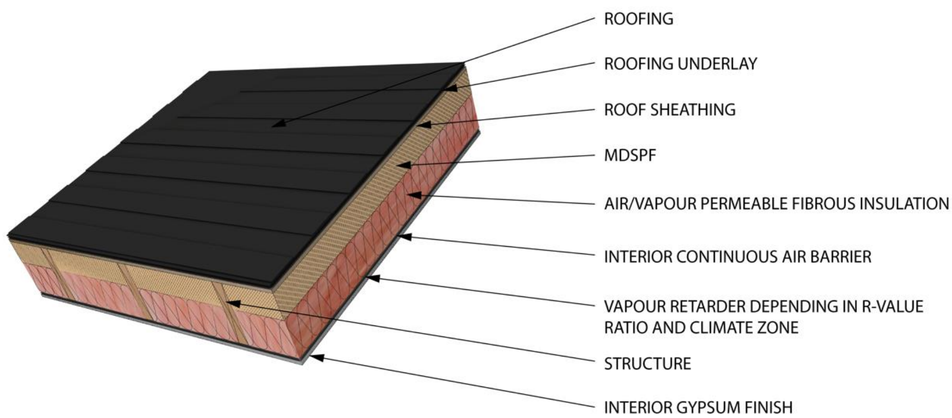

Figure 10 : Hybrid roof assembly combination of air impermeable exterior MDSPF insulation installed against the interior of the roof sheathing and air/vapour permeable fibrous insulation to the interior of the spray foam.

As discussed previously, the spray foam material is an air barrier everywhere it is continuous within the roof assembly, so if the framing can be encapsulated and the spray foam is continuous over the framing as shown in Figure 11, the joints between built up framing can not result in air leakage to the roof sheathing. It is recommended to encapsulate framing that is partially embedded in SPF whenever possible. However, it may not be possible to fully encapsulate the framing of the roof assembly in assemblies that require the interior gypsum to be installed against the interior surface of the framing such as rafters of a cathedral ceiling. In this case, with built up, or adjacent, framing, the air barrier system must be continuous over the joint between the framing, and the joint must be sealed. Tape works well to seal this joint. Sealant can work, but care must be taken, as wood drying, and shrinking of wood can cause sealants to fail at the joint.

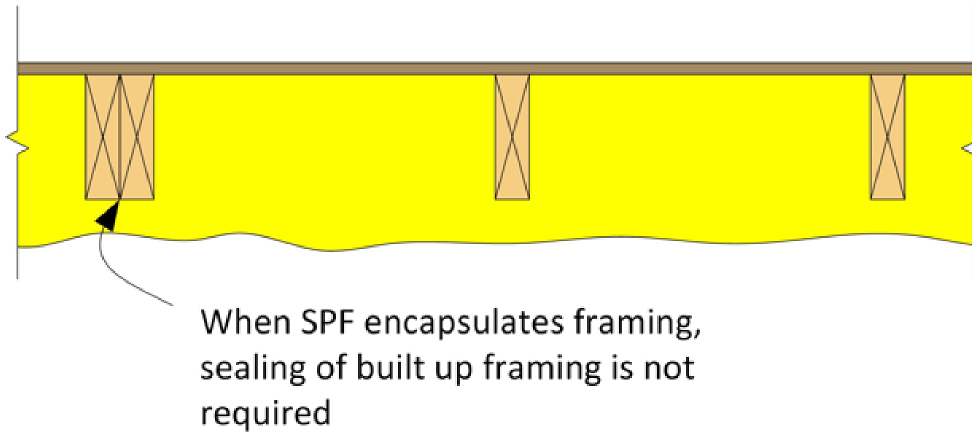

Figure 11 : Framing embedded in SPF should be encapsulated when possible to ensure air barrier continuity around the roof framing. (credit image to SFC[3])

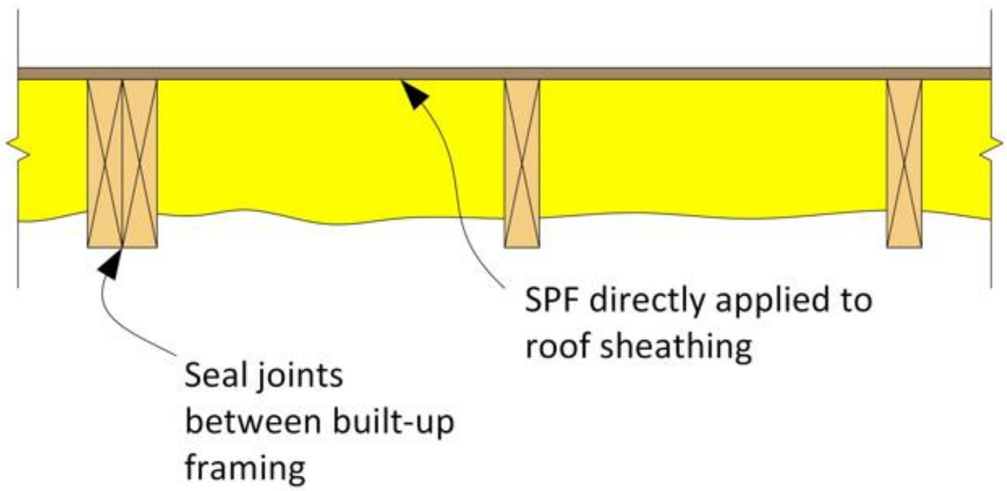

Figure 12 : In many cases, such as cathedral ceiling rafters, it is not possible to encapsulate framing, with SPF, and the joint between built up framing must be sealed by alternative means continuously along the entire length. (credit image to SFC[3])

[3] Spray Foam Coalition. Installing High Performance Insulation Part 3: A Guide to Installing Unvented Attics in Canada. American Chemistry Council. https://www.americanchemistry.com/industry-groups/spray-foam-coalition-sfc/spray-foam-coalition-canadian-resources.

4 Literature Review

There have been many studies conducted on the measured and predicted performance of unvented roof assemblies. All of the reviewed reports have been provided as a separate appendix in support of this report.

An extensive literature review regarding sloped wood-framed roof assemblies was conducted[4] and presented at the 15th Canadian Conference on Building Science and Technology in 2017. The conclusion of the peer-reviewed conference paper was that the construction industry has the required information and experience from Canada, the United States, and elsewhere, to design moisture safe unvented roof assemblies for all climate zones in Canada utilizing appropriate design and existing construction technology.

A hygrothermal analysis study in 2010[5] looked at the predicted performance of different unvented roof assemblies, with various insulation strategies including full-depth MDSPF, and a combination of MDSPF with spray fiberglass to the interior in various climates in the United States. All of the roof assemblies were north-facing with a 3:12 pitch. One of variables of the study was the colour of the roofing which affects the solar absorption and energy available for drying within the roof assembly. It was found that in Climate Zones 6 and 7, the full-depth MDSPF roof assembly did not show any risk of moisture accumulation in the sheathing with dark asphalt shingles, even with an elevated interior relative humidity, for each cardinal orientation. The assembly with 4" MDSPF and spray fiberglass performed the same. If the same insulation strategies were clad with a light metal roof with more solar reflection and less solar absorption, then the predicted sheathing moisture contents were still acceptable at recommended interior relative humidity levels, but did have a predicted elevated sheathing moisture content when the interior relative humidity was higher than recommended. Elevated interior relative humidity levels will put all roof (vented or unvented) and wall enclosure systems at a higher risk of cold weather moisture accumulations.

There have been other studies that look at the impact of solar absorption of the roof related to moisture accumulation and durability. For example, one study by Nusser et al.[6] of unvented low-slope roofs with mineral wool batt insulation conducted in Europe investigated the measured performance differences between full-scale test hut roofs with different amounts of solar absorption, and different interior smart vapour barrier membranes. It was concluded that low temperatures on the roof, whether from shading or a green roof, lead to high and long-lasting relative humidity in the cavity.

On a similar topic to Nusser et al., Kehrer and Pallin[7] also found in their hygrothermal study that the colour and solar reflectance of the roof surface is very important. The amount of accumulated moisture is almost doubled in cool roof (white) construction compared to a traditional black roof under certain modeled parameters, but the factor of

[4] Smegal, J. et al. State of the Art Review of Unvented Sloped Wood-framed roofs in cold climates. 15th Canadian Conference on Building Science and Technology. Paper 106. 2017
[5] Straube, J., Smegal, J., and Smith, J. 2010. Moisture-safe unvented wood roof systems. *In* Proceedings of Building Enclosure Science & Technology, Portland, Or, 12-14 April 2010. National Institute of Building Sciences, Washington, DC.
[6] Nusser, Bernd et al. 2010. "Low-Pitched Timber Roofs". World Conference on Timber Engineering
[7] Kehrer, Manfred and Simon Pallin. 2013. "Condensation Risk of Mechanically Attached Roof Systems in Cold Climate Zones.

safety with moisture-related durability is higher in all low-slope roofs with the high solar absorption of dark roof membranes.

A field study was conducted between 2010 and 2012 on unvented and vented roof assemblies in Waterloo, Ontario (CZ6, 4200HDD). Following the field monitoring study, a hygrothermal model was correlated to the monitored data to predict the performance in other Canadian climate zones[8]. The hygrothermal analysis was very conservative in nature using the coldest weather data available, north steep slope orientations with very little solar energy, and elevated interior relative humidity levels.

It was found that even under very conservative prediction criteria for climate zones up to 7A (5777 HDD 18) that , it was found that an unvented full MDSPF application did not result in increased sheathing moisture content with a recommended interior relative humidity of 30% RH. With elevated interior relative humidity every year, and the coldest weather data available to the model, there were some eventual elevated sheathing moisture contents on the north orientation following repeated years of analysis.

A CMHC document titled Arctic Hot Roof Design[9] was published in 2001 explaining the benefits of an unvented exterior insulated roof assembly with board foam insulation compared to a typical ventilated attic assembly, minimizing the risk of attic condensation related to air leakage, and minimizing the risk of snow blowing into the attic. Short construction seasons, expensive construction materials and seasonal temperature limitations in the far north (ie. CZ8) can make all construction more difficult, so picking a long lasting durable solution is even more important.

Based on a review of the literature, it is conclusive that full depth MDSPF, continuous exterior insulation, or a combination of both to meet the effective R-value requirements can provide a durable high performance unvented roof assembly in cold climates.

5 Other Considerations for Unvented Roofs

5.1 Roof Underlay in Sloped Roofs

Because an unvented roof assembly with full depth MDSPF is unable to dry sufficiently to the interior, it is critical that the wood sheathing not get wet and/or remain wet for extended periods. In a typical shingled or metal roof assembly, the manufacturer's recommended best practices for roofing underlayment should be followed, this typically requires a self-adhered membrane (i.e. ice and water shield) in some areas to minimize the risk of water ingress from ice damming, combined with a synthetic underlay over the remainder of the roofing assembly. Some manufacturers even recommend a self-adhered membrane beneath the whole roof system. The traditional building paper or felt paper should not be used in unvented roof assemblies because it tends to break down more quickly and may not provide a continuous water control layer for the life of the roofing.

5.2 Interior Relative Humidity

All of the design criteria and recommendations included in this report are based on the assumption that the interior relative humidity in the winter is controlled within the

[8] Smegal, Jonathan and John Straube. 2014. "Ventilation and Vapor Control for SPF-Insulated Cathedral Ceilings." Report by Building Science Consulting Inc. in coordination with the University of Waterloo Building Engineering Group BEGHut for the Canadian Urethane Foam Contractors Association Inc., Waterloo, ON.
[9] CMHC About Your House, North Series 6, Arctic Hot Roof Design. 2001

building. The winter time interior relative humidity in cold climates plays an important role in the durability of all enclosure components. In the Appendix of the NBC (A-9.25.5.2) it states that one of the assumptions for enclosure durability in cold climates is that the winter time relative humidity does not increase above 35%. Further to the statement in the building code, in extremely cold climates, (ie. climate zones 7B and 8), lowering the winter time interior relative humidity into the 25-30% range would minimize durability enclosure risks further.

5.3 Fire Codes

The use of spray foam in an unvented cathedralized attic application typically means the foam is left exposed on the underside. There are restrictions for accessible spaces with regards to the exposure of foam plastic such as spray foam insulation (NBC 9.10.17.10) that require the covering of the spray foam with an approved material from the list in NBC 3.1.5.15.(2) or an approved intumescent paint depending on local code requirements and the accessibility of the enclosed space.

However in an attic or roof space that is considered 'concealed', the ceiling gypsum board below the attic or roof assembly will provide the required thermal protection. NBC A-3.1.4.2.(1) defines a concealed space as any space that is not visibly apparent and that is provided with an opening to allow access for repair and periodic inspections.

5.4 Stacked Framing

Spray foam adhered to the framing makes an excellent air barrier, however, there are some areas where spray foam can not be installed, such as side-by-side, or stacked, framing members that will result in an air leakage pathway between the framing in the same wall or between the framing of different assemblies (ie. sloped roof and gable end). A continuous bead of sealant installed between the framing members during construction, or a layer of tape or flashing membrane installed continuously on the interior surface of the wood post construction are the two preferred options for sealing the gaps between the framing against air leakage. Alternately in an attic, spray foam can encapsulate the built up framing to form a continuous barrier against air leakage.

5.5 Vapour Permeance of Wood Framing

In unvented spray foam roof assemblies where the MDSPF fills the cavities between the structure, and the interior of the structure is left exposed, it is clear that the MDSPF has sufficient vapour control to meet the code requirement, but there is some uncertainty regarding the vapour permeance of the rafters. This is a common question, and has been addressed previously to show that wood framing does provide sufficient vapour control.

As with most other hygroscopic materials, the vapour permeance of wood varies depending on the surrounding relative humidity. An Exova test report in 2009 measured the vapour permeance of 2x4 and 2x6 wood framing according to ASTM E96 under both dry (0% RH and 50% RH) and wet (100% RH and 50% RH) cup conditions. The results are shown in the table below.

To meet the prescriptive vapour barrier requirement of the NBC, the vapour permeance of the structure must be less than 57 $ng/Pa \cdot s \cdot m^2$ or approximately 1 US Perm.

TABLE 4 : MEASURED VAPOUR PERMEANCE OF WOOD FRAMING*		
TEST SAMPLE	TEST CONDITIONS	TEST RESULT [Perms]/[ng/Pa·s·m²]
2x4	Dry Cup (0%RH and 50% RH)	0.63 / 36
2x4	Wet Cup (100% RH and 50% RH)	0.72 / 41
2x6	Dry Cup (0%RH and 50% RH)	0.52 / 30
2x6	Wet Cup (100% RH and 50% RH)	1.03 / 59

* Exova Report N. 09-06-M0097

Another source of material data for wood vapour permeance is the ASHRAE HOF Vapour Permeance Tables. Several wood species have vapour permeance test data for transverse wood grain samples at a range of relative humidities. For all of the transverse wood measurements tested at a relatively humidity of 70% or less, the vapour permeance of 6 inches (152mm) ranged from 0.1 perms (5.74 ng/ Pa·s·m²) to 1 perm (57.4 ng/ Pa·s·m²). This means that based on the test results, and available literature, the framing does meet the vapour barrier requirements in unvented roof assemblies with the full R-value installed as MDSPF. The vapour permeance of OSB as found in the web of TJI joists would also meet the vapour permeance requirements as per OSB vapour permeance values found in the ASHRAE HOF. rubble crawlspace

6 Conclusions/Recommendations

Based on a review of the moisture physics, building codes, and literature review, it's clear that unvented sloped and low-slope roof assemblies will safely function in the province of Alberta and three prescriptive types of roof assemblies should be allowed in Part 9 construction as it will satisfy the requirements of Section 9.19.1.1 (1) of the NBC related to roof ventilation.

1. Sloped or low-slope roof assembly with the entire required R-value installed on the exterior of the structure as rigid or semi-rigid insulation. A continuous and effective air and vapour barrier is required on the roof sheathing at the interior of the insulation to prevent moisture movement by air leakage or vapour diffusion into the roofing insulation.

2. Sloped or low-slope roof assembly with the entire required R-value to meet the effective R-value requirements installed as SPF directly to the underside of the roof sheathing. MDSPF includes vapour control, and no additional vapour control is required, however if LDSPF is used, then a continuous effective vapour control in direct contact with the LDSPF, and sealed around penetrations, is required to minimize vapour diffusion and moisture accumulation within the roof system.

3. A combination of exterior rigid or semi-rigid insulation installed on the exterior of the roof structure combined with medium density MDSPF installed directly to the underside of the roof sheathing. With MDSPF, no additional vapour control is required. If LDSPF is used instead, then vapour control may be required depending on the R-value ratio of the insulation types, and the vapour permeance of the exterior insulation. The use of LDSPF should be analyzed on a case-by-case basis.

As with any building enclosure component, good design and construction is required to ensure long-term durability and performance. Failure to meet the design or construction standard of care could result in failures of even the most durable and safe assemblies.

There are several criteria, in addition to the basic assembly, to minimize the risk of air leakage and potential moisture accumulation within the unvented roof assembly.

- Interior winter time relative humidity is controlled. This is also important for all other enclosure assemblies (not just roofs), and to control condensation on the interior of windows.
- Spray foam must be installed in accordance with CAN-ULC-S705.1or CAN-ULC-S712.1 and CAN-ULC-S705.2 or CAN-ULC-S712.2. This means that all criteria related to substrate moisture contents/temperatures, pass thicknesses, daily testing, daily logs, etc. must be followed during installation.
- In a roof assembly insulated and air sealed with SPF, all stacked framing members, and interfaces between assemblies (ie. roof to wall, or sloped roof to gable, etc) that can not be sealed with spray foam are well sealed by alternative means (typically a tape product).
- The spray foam shall be installed by an installer that has successfully completed a training course and is certified as a Spray Polyurethane Foam Installer (Section 4.3.4, CANULC S705.2 or CAN-ULC S712.2

If you have any questions when you've reviewed this report in its entirety, please do not hesitate to contact us by phone or email.

Yours truly,

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