ICYNENE INC.

Research Summary: Field Performance of ocSPF-Insulated Unvented Roof Assemblies in the Climate of Vancouver, British Columbia, Canada

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1. Introduction

This document provides a summary of research work that Building Science Consulting Inc. (BSCI) has done over the last decade to measure and assess the field performance of ocSPF-insulated unvented roof assemblies in the climate of Vancouver, BC, Canada. The Vancouver area is in US DOE Climate Zone 4C, and is typical of the Pacific Northwest.

2. Background

Conventional Ventilated Roof Assemblies

Most low-rise residential buildings in Vancouver and the Lower Mainland of BC employ roof assemblies designed around the conventional ventilated attic. These roof assemblies are most commonly wood-framed with roof slopes or "pitches" in the range of 4 in 12 to 12 in 12 (i.e. 18.5° to 45°). Insulation is typically installed on the topside of the ceiling plane or "floor" of the attic space. The attic space (i.e. the volume between the top of the ceiling and the underside of the roof deck or sheathing) is ventilated to encourage the removal of incidental moisture and heat. Figure 1 shows the configuration and components of a conventional ventilated attic roof assembly.

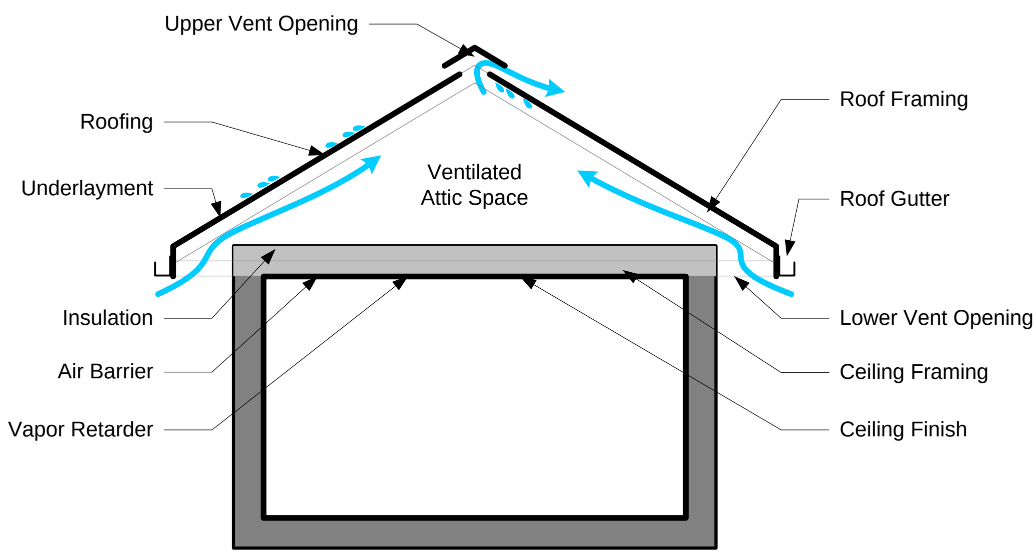

Figure 1 – Ventilated Attic Roof Assembly (Schumacher 2008)

Ventilated cathedral ceiling roof assemblies differ from conventional ventilated attic roof assemblies only in their geometry: the ceiling is moved off the horizontal plane and sloped (at a pitch equal to or slightly less than the pitch of the roof deck) to increase the floor-to-ceiling height in the occupied space. Figure 2 shows the configuration and components of a cathedral ceiling roof assembly. These roof assemblies are constructed using scissor trusses (a very shallow attic space is created between the upper and lower cords of the truss) or by installing the ceiling finish directly on the underside of the rafters. In either case it is common to install insulation on the topside of the ceiling while maintaining a minimum 63 mm (2.5 in.) deep ventilated space or "gap" between the top of the insulation and the underside of the roof deck. Again, the ventilated air space is intended to encourage the removal of incidental moisture and heat.

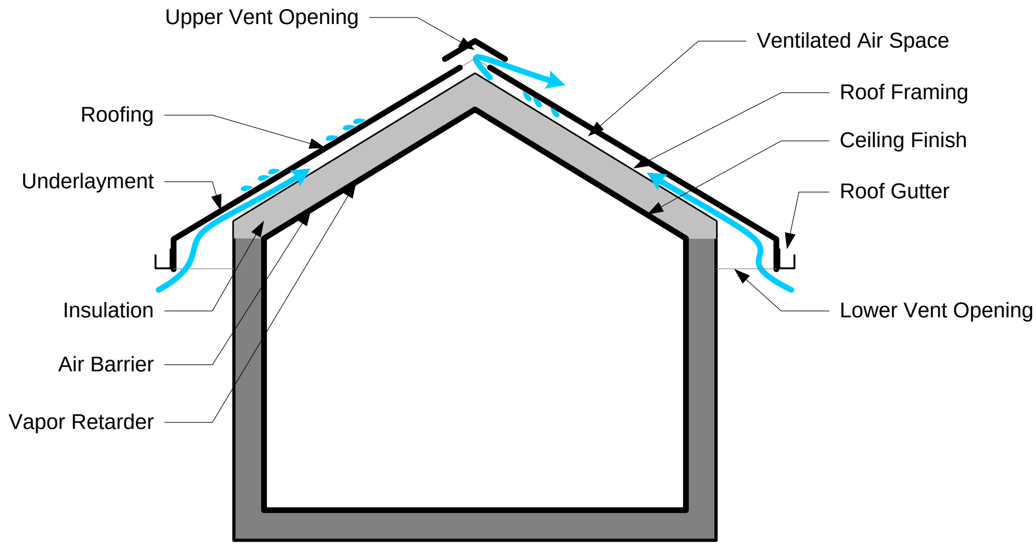

Figure 2 – Ventilated Cathedral Ceiling Roof Assembly (Schumacher 2008)

Local and Canadian building codes require ventilated attics be provided with vents having an unobstructed opening area greater than 1/300 of the insulated ceiling area. Where roof assemblies have a slope of less than 2 in 12, or where the roof assembly creates a cathedral ceiling, the required opening area is increased to 1/150 of the insulated ceiling area. The code provides further requirements to assure that vent openings are roughly uniformly distributed over opposite sides of the building and between the top and bottom of the ventilated attic space or, in the case of the cathedral ceiling, ventilated air space.

The Argument for Eliminating Roof Vents

The code requirements for ventilation of roof assemblies are intended to minimize the potential for moisture problems in ventilated attics and cathedral ceilings. However, there are compelling arguments for eliminating vent openings from roof assemblies:

- In ***wildfire zones*** vented soffits and eaves have been demonstrated to contribute to the rapid spread of fire into the structure. (Quarles 2002, Rose and TenWolde 2002). Many houses in the Lower Mainland of BC are located in or immediately next to forested areas that are prone to wildfire.
- In ***high wind regions*** air enters the vents on the windward side of the building, pressurizing the roof, increasing uplift and the potential for wind-related damage.
- Where ***wind and precipitation*** occur simultaneously rain or snow can be carried into roof vents and deposited inside the roof assembly where it may come into contact with insulation or moisture sensitive materials. This problem is particularly relevant in the climate of Vancouver and the Lower Mainland where there are many hours of light rainfall – smaller droplets of water are more easily carried into vent openings.
- On the ***coast line*** salt spray can also be carried into vent openings, where it can accelerate corrosion of metal structural components such as truss plates and steel beams.
- In ***coastal climates with prolonged periods without warm temperatures or sunshine*** (as is the case in the Vancouver and the Lower Mainland) ventilation may not have sufficient capacity to remove moisture from a roof assembly and, when sheathing temperatures are cool, may even add moisture to it. Canada Mortgage and Housing (CMHC) field surveys identified a pattern of moisture problems in ventilated attics in such climates (Walker and Forest 1995).

Vent openings and ventilated attic or air spaces are associated with a number of other building science problems (e.g. HVAC-related, acoustic, etc.). Unvented roof assemblies have been proposed as a strategy to address the problems associated with roof vents and ventilation.

Unvented Roof Assemblies

Unvented roof assemblies have been adopted in all climate zones throughout North America. Their increasing popularity is driven by a number of design, construction and performance benefits: complex roof and ceiling geometries can be constructed without the need for convoluted ventilation strategies; in cathedral ceiling roof assemblies the elimination of a ventilation air space makes room for higher levels of insulation; compact roof assemblies can be constructed without concern over the effectiveness of ventilation air spaces; effective air barrier systems can be more easily and reliably installed (i.e. at the underside of the roof rather than the ceiling where they are compromised by numerous lighting and mechanical penetrations); moisture sensitive materials such as ceiling finishes are protected from wetting due to wind-driven snow / rain or moist coastal air; and finally, unvented roof assemblies also create conditioned spaces in which HVAC equipment and ductwork can be installed (thus minimizing the potential for air leakage or cold surface condensation).

Two types of unvented roof assemblies are employed: unvented cathedralized attic (a.k.a. conditioned attic) roof assemblies, and unvented cathedral ceiling roof assemblies.

Figure 3 shows the configuration and components of an unvented cathedralized attic roof assembly. The geometry of an unvented cathedralized attic roof assembly is the same as a conventional ventilated attic roof assembly; the roofing is installed over a sloped surface that is supported by one structural member while the ceiling finish is installed on a horizontal plane and supported by a different structural member. The main difference between the two types of roof assemblies is in the location of the control layers: the air barrier system, vapor retarder (if applicable) and insulation. In the ventilated attic these are all located at or immediately on top of the ceiling finish. In the unvented cathedralized attic the insulation is installed in direct contact with the underside of the roof sheathing, the air barrier and vapor control layers are either integral with the insulation material or installed over the inside face of the insulation.

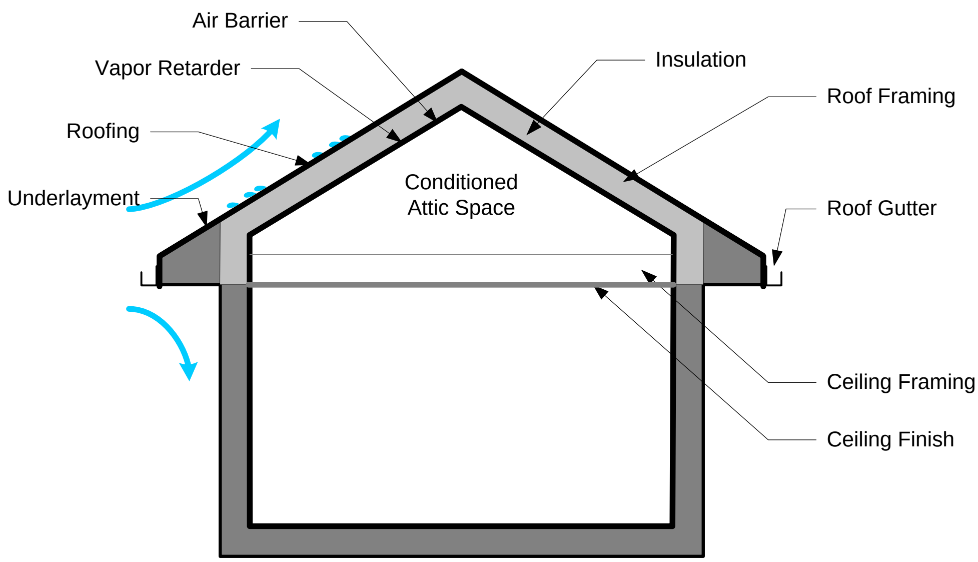

Figure 3 – Unvented Cathedralized Attic Roof Assembly (Schumacher 2008)

Figure 4 shows the configuration and components of an unvented cathedral ceiling roof assembly. Again, the geometry of an unvented cathedral ceiling roof assembly is similar to a ventilated cathedral ceiling roof assembly: the roofing is installed over a sloped surface that is supported by one structural member; the ceiling finish is installed on the underside of the same structural member or another sloped structural member below the roof plane.

The control layers in the unvented cathedral ceiling roof assembly are located in the same locations as those in the unvented cathedralized attic: insulation is installed on the underside of the roof sheathing; the air barrier and vapour control layers are either integrated with the insulation or installed on the inside of it. The main difference between the unvented and ventilated cathedral ceiling roof assemblies is the absence of a ventilated air space in the unvented assembly (the insulation is installed tight against the underside of the roof sheathing).

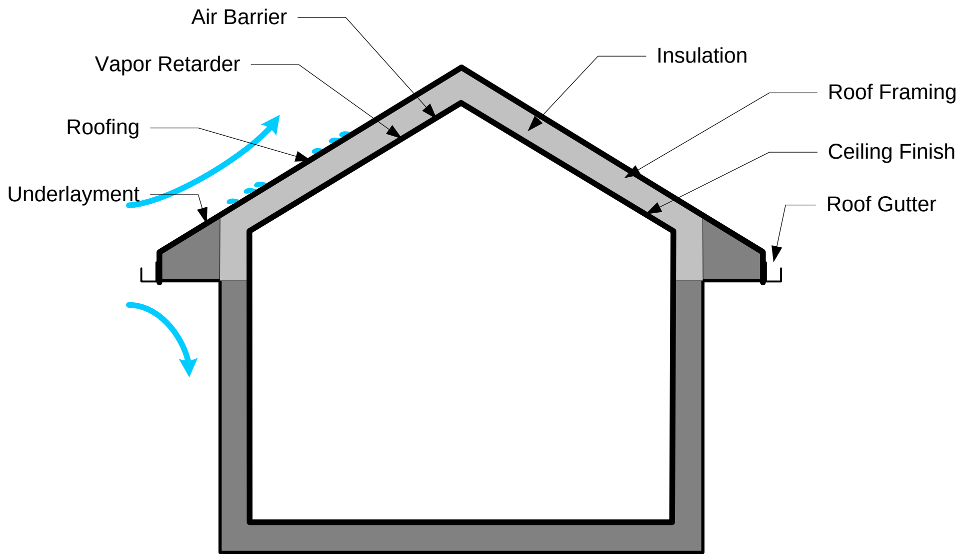

Figure 4 – Unvented Cathedral Ceiling Roof Assembly (Schumacher 2008)

ocSPF-Insulated Unvented Roof Assemblies

In Vancouver and the Lower Mainland of BC open-cell spray polyurethane foam (ocSPF) has been employed as an insulation application in the earliest unvented cathedralized attics and unvented cathedral ceilings. Well-developed solutions exist to satisfy the building enclosure control functions in ocSPF-insulated unvented roof assemblies:

Control Bulk Water:

Bulk water control is absolutely critical for any roof assembly. Unvented roof assemblies use the same water management strategies, materials and details as their ventilated counterparts. In sloped roof assemblies bulk water (i.e. rain water, melt water) shed from the surface of the roofing material, collected in the roof gutters, then direct down and away from the building. Underlayment materials are typically installed between the roofing material and top of the sheathing to provide a drainage plane for any incidental moisture that penetrates the roofing. “Eaves protection” may be installed at critical locations to provide improved protection against ice daming or a concentration of liquid water. Flashings (e.g. wall-to-roof, kickout, etc.) and drip edges protect roof penetrations, wall-to-roof intersections, and walls below roof overhangs.

Control Heat Flow:

Heat flow control is accomplished through the application of insulation. In ocSPF-insulated unvented cathedralized attics and unvented cathedral ceilings, open-cell spray polyurethane foam is sprayed directly against the underside of the roof sheathing so it fills the space between the structural members (e.g. the rafters or truss top chords). If ocSPF is the only insulation material in the assembly it must be installed to sufficient thickness to satisfy the thermal control function of the roof assembly. In most cases the minimum installed thickness will be determined on the basis of local building code requirements.

Control Airflow / Air Leakage:

Airflow / air leakage control is accomplished through the design, fabrication and commissioning of an air barrier system. At typical roof insulation thicknesses (e.g. over 5.5 in. or 140 mm) ocSPF insulation is air impermeable; it bonds well to the wood framing and sheathing substrates so, in ocSPF-insulated unvented roofs, the insulation plays an important role in creating an air barrier system. To satisfy the air leakage control function of the roof assembly ocSPF must be installed without any gaps, and joints between other materials (e.g. wood-to-wood joints between double top plates, double rafters, etc.) must be separately sealed and the roof air barrier system must be made continuous with the wall air barrier system and across any windows, skylights, mechanical penetrations, etc.

Control Vapour Diffusion:

Vapour diffusion control should consider outward diffusion when the outdoor air and/or roof sheathing temperatures are cooler than indoor air temperature (and dewpoint), and inward diffusion when outdoor air and roof sheathing temperatures are higher than indoor.

Open-cell spray polyurethane foam insulation is relatively vapour permeable (e.g. roughly 1200 ng/Pa.s.m2 for 25 mm thickness or 21 US perms for 1 in.) so water vapour will diffuse through the insulation. In roof applications this can be of benefit in the event that moisture is built-in or penetrates into the roof sheathing. Under favourable conditions (i.e. when the roof sheathing is warmer than indoor air) the vapour permeable ocSPF can allow drying to the indoor side of the assembly (i.e. inward diffusion). However, in cold climates wintertime outward diffusion can cause some moisture accumulation in the roof sheathing.

Additional vapour control layers (e.g. painted drywall, smart retarder membranes, etc.) can be installed on the indoor side of the ocSPF insulation to limit outward (i.e. wintertime) vapour diffusion through the assembly. There has been some debate about the amount of additional vapour control necessary. Too much vapour diffusion might result in an excess of wintertime moisture in the sheathing; too little vapour diffusion might prevent inward drying.

Any roof assemblies (regardless of whether it is ventilated or unvented) must be designed to maintain a moisture balance. In an ocSPF-insulated unvented roof assembly moisture balance is maintained when the rate and amount of moisture accumulation during the wetting period (i.e. winter) can be safely stored in the material / system then removed from the assembly during the drying period (i.e. spring / summer).

Over the past decade BSCI has conducted a number of studies to measure and assess the field performance (specifically vapour control and moisture balance) of ocSPF-insulated unvented roof assemblies in the climate of Vancouver and the Lower Mainland of British Columbia. A summary of that work is provided in Section 2 of this document.

3. BSCI osSPF-Insulated Unvented Roof Research in Vancouver BC

BSCI staff conducted two studies to measure and assess the field performance of ocSPF-insulated unvented roof assemblies in Vancouver BC: 2004 through 2006 the team monitored the field performance of an ocSPF-insulated unvented cathedral ceiling in a single detached home in Dunbar-Southlands; 2005 through 2007 the team compared the field performance of two ocSPF-insulated unvented cathedralized attics and one conventional ventilated attic in a test hut facility in Coquitlam.

Dunbar-Southlands House Roof

BSCI conducted the Dunbar-Southlands House study in conjunction with Icynene Insulation. The house was designed as a new-build demonstration of ocSPF-insulated wall and roof assemblies. The ocSPF unvented cathedral ceiling roof assembly comprises asphalt shingles, 12.5 mm (0.5 in.) plywood sheathing, 38 x 89 mm (2 x 4 in.) horizontal wood strapping at 406 mm (16 in.) OC, 38 x 228 mm (2 x 10 in.) wood rafters at 406 mm (16 in.) OC, with 16 kg/m3 (0.5 pcf) ocSPF insulation, 12.5 mm (0.5 in.) painted gypsum drywall. Figure 5 shows the construction and instrumentation of the roof assembly. Together the horizontal strapping and rafters result in a 266 mm (10.5 in.) deep cavity. The ocSPF insulation was installed to fill nearly all of this space.

The assembly did not employ a vapour retarding membrane (e.g. 6 mil poly). The experimental program was conceived to assess the vapour control provided by the painted drywall interior finish (with primer and 2 coats of latex paint) and the resulting moisture balance achieved in the roof assemblies.

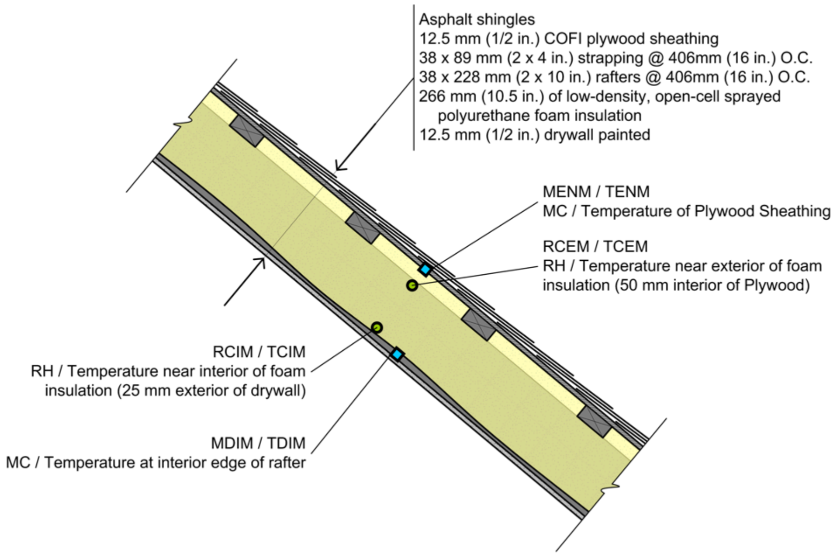

Figure 5 – Dunbar-Southlands House ocSPF-insulated Cathedral Ceiling

A roof-monitoring package was designed to measure and record the temperature and relative humidity at the inside face of the ocSPF insulation and at a depth of 38 mm (1.5 in.) from the outside face of the ocSPF insulation. Moisture content was measured near the inside face of the wood rafter and at mid-thickness through the roof sheathing. This monitoring package was installed at 4 locations on the South-facing roof and 4-locations on the North-facing roof.

Figure 6 shows the monitoring locations for the roof (and wall) assemblies at the Dunbar-Southlands house. The following monitoring location nomenclature was used for the roof assemblies:

- R = Roof monitoring location
- S = South-facing roof slope, N = North-facing roof slope
- W = West end of roof, E = East end of roof
- U = Upper monitoring location, L = Lower monitoring location

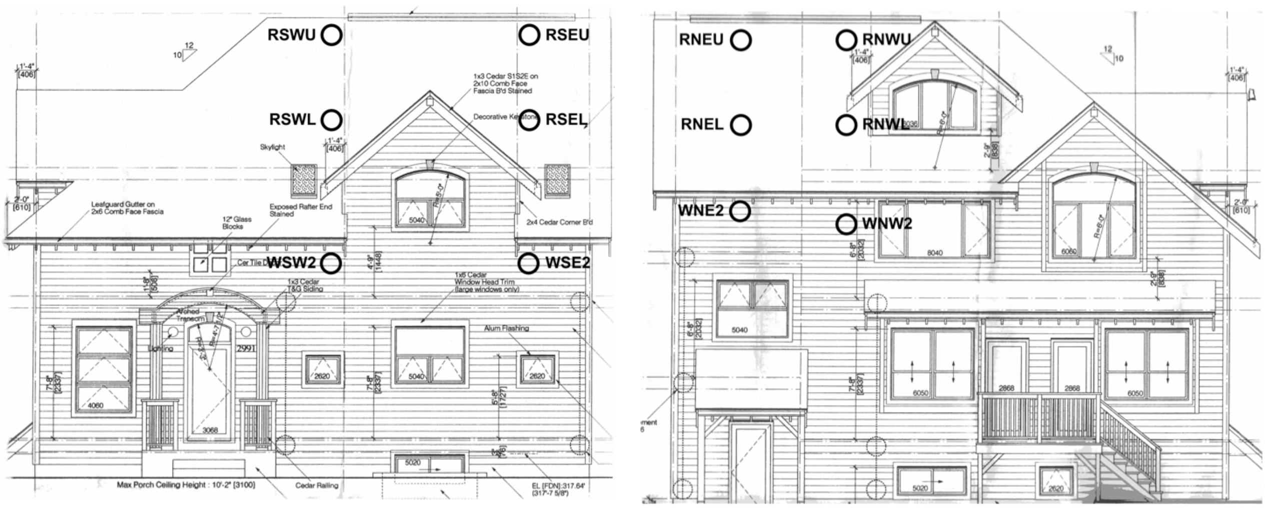

Figure 6 – Monitoring Locations on the South-facing (left) and North-facing (right) Roof Slopes

Monitoring equipment was also installed to measure and record indoor and outdoor temperature and relative humidity, solar radiation, and the presence of moisture (e.g. condensation / frost / rain) on top of the roofing. Readers are directed to Schumacher and Reeves Buildings 10 conference paper for detail regarding the monitoring setup and results (Schumacher and Reeves 2007).

Two full winters were included in the study period. Wintertime indoor temperatures were maintained around 21°C (70°F); relative humidity was maintained around 35 to 40%; and indoor dewpoint temperatures tended between 5 and 8°C (41 and 46°F). Figure 7 shows the measured indoor temperature, relative humidity and dewpoint over the study period. The wintertime dewpoint conditions are identified by the two black boxes in the lower part of the image.

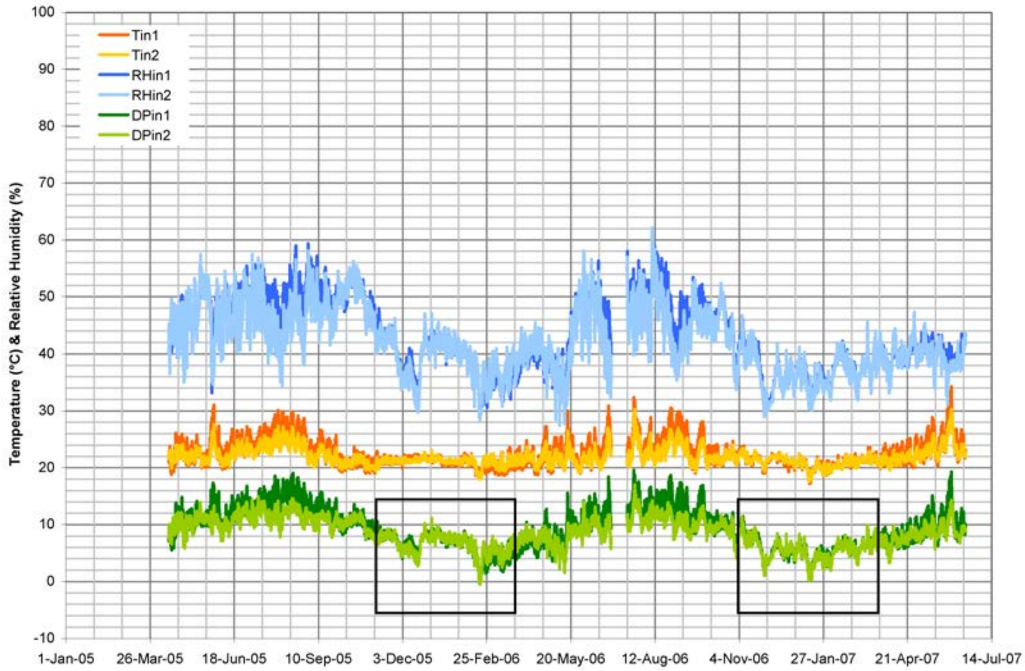

Figure 7 – Indoor Temperature and Humidity Conditions Recorded During the Dunbar-Southlands Roof Study

Figure 8 shows the measured sheathing moisture content at the south- and north-facing monitoring locations (orange and blue traces respectively) of the Dunbar-Southlands house. Lower moisture content readings are constantly recorded at the south-facing locations. This should be expected as the south-facing slope receives more solar radiation so roof temperatures on the south face are higher and there is more frequent drying to the indoors (i.e. inward vapour diffusion), even during the colder winter months. The end result is lower equilibrium moisture content in the sheathing on the south side of the building.

On the north side of the building the sheathing moisture content starts out high as a result of moisture that was built-in during construction over the last few months of 2014 and first few months of 2015. The monitored data indicate that the north-facing roof sheathing dries quickly in the spring as outdoor temperatures warm and the roof is exposed to longer periods of more intense solar radiation. North-facing sheathing moisture contents pick up again when outdoor temperatures cool off in the fall and drop again the next spring. The pattern of annual moisture accumulation (in the fall through winter) and drying (in the spring through summer) continues.

Peak sheathing moisture contents measured in the first full winter were not as high as the initial moisture content. Similarly, peak sheathing moisture contents measured in the second full winter was not as high as in the first. It takes a few years for the built-in moisture to dry out of the system. This trend, noted in several field research studies, can be explained by "ping-pong moisture".[1] If a vapour barrier (i.e. a material having less than 60 ng/Pa.s.m2 or 1 US perm) were applied on the indoor side of the assembly, ping-pong water could bounce back and forth for years without drying out of the system.

[1] When sheathing dries out in the spring, some of the built-in moisture dries through the drywall and is removed from the system while some of the built-in moisture redistributes to other materials (e.g. wood rafters, drywall, etc.) and is retained in the assembly. In the fall, the moisture retained in the materials at the indoor side of the assembly is released and redistributes to the materials at the outdoor side of the assembly (i.e. the roof sheathing). This "ping-pong" moisture mechanism continues year after year until the annual moisture balance reaches equilibrium with the indoor and outdoor climate.

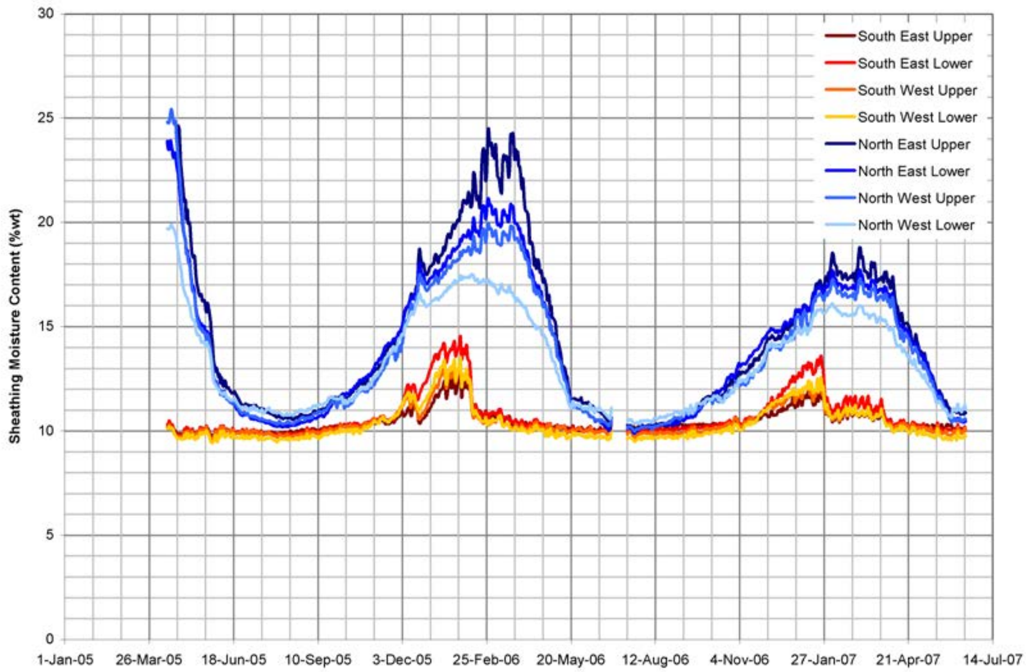

Figure 8 – Sheathing Moisture Content Recorded During the Dunbar-Southlands Roof Study

1 Year Inspection Openings

For wood and wood-based materials such as plywood roof sheathing, 20% moisture content is often cited as an upper threshold for acceptable performance. The north-facing sheathing moisture contents at the Dunbar-Southlands house exceeded this 20% threshold when the assembly was closed in spring of 2005 and again over the first fully occupied winter (January through April of 2006). In June of 2006 BSCI made a visit to the Dunbar-Southlands house to visually inspect the plywood roof sheathing. Inspection openings were made near locations RNEL, RNWL and RSWL. A 150 mm (6 in.) diameter disk of drywall was cut and the ocSPF insulation was carefully removed to expose the indoor face of the plywood sheathing. Figure 9 shows the inspection opening made at location RNEL. The black dots visible in the right photo are holes from the handheld moisture meter. Handheld meter readings agreed well with the in-situ monitoring system. None of the test cuts showed any signs of mold or decay, the interior surface of the plywood was clean and the material resisted penetration of the moisture meter pins and the point of a pocket knife just as new plywood sheathing would.

Figure 9 – Dunbar-Southland House – Jig and Core Through Drywall (left) and Foam Cut to Interior of Plywood (right)

Mold index

More recently BSCI revisited the data from the Dunbar-Southland roof study. We extended our previous performance analysis, using the revised VTT mold growth model (Ojanen et. al. 2010) to calculate the mold index at location RNEU (i.e. the location that had the highest recorded sheathing moisture contents). BSCI expects the revised VTT model to be adopted by industry standards for moisture-control design of buildings. The model accounts for measured or predicted (if using a hygrothermal model) temperature, relative humidity, material mold sensitivity, and mold index decline (due to unfavourable temperature or moisture conditions). A mold index of 3 (onset of visible mold growth) is considered the upper threshold for acceptable performance.

Figure 10 shows the mold index calculated using the temperature and relative humidity data collected from the RNEU monitoring location during the Dunbar-Southfield roof study. For these calculations we assumed a sensitive material and two different mold index decline values ("almost no decline" and "relatively low decline"). The calculated mold index remains well below the threshold of 3, even through the periods of high wintertime humidity.

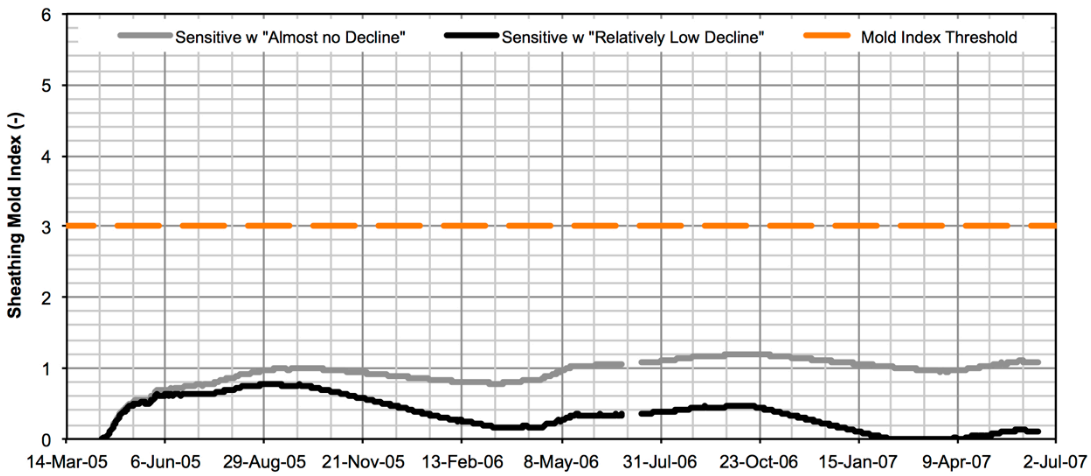

Figure 10 – Calculated Mold index for Roof Sheathing at Location RNEU, Dunbar-Southfield Roof Study

Coquitlam Test Hut Roofs

Since 2005 BSCI staff have operated the Coquitlam Test Hut as a joint project with Gauvin Construction in Coquitlam, BC. This test hut was designed to facilitate field exposure assessment of full-scale roof and wall assemblies in the climate of Vancouver and the Lower Mainland. The structure is located on the rooftop of a three storey commercial building so test walls are exposed to unobstructed weather approach from all directions. The test hut accommodates seven 1.2 x 2.4 m (4 x 8 ft.) test wall assemblies on each of the North, East, South, and West orientations plus three 1.8 x 5.4 m (6 x 18 ft) test attic / roof assemblies, each with North and South-facing roof slopes.

Figure 11 – Coquitlam Test Hut

The Coquilam Test Hut roof study made use of all three of the test attic / roof assemblies. The first attic space was setup as a conventional ventilated attic roof assembly with batt insulation on the attic floor. A polyethylene vapour barrier was installed at the ceiling plane and sealed as the air barrier system (i.e. to isolate the attic space from the room below). Gypsum wall board (GWB) was installed (taped and painted) on the underside of the bottom truss chords to create the ceiling finish for the room below. The roof was sheathed with 13 mm (0.5 in.) oriented strand board (OSB) and this was covered with a #15 felt underlay. Asphalt composite shingles were installed as the roofing. Figure 12 shows the construction and instrumentation of Roof 1, the Ventilated Attic assembly.

The remaining two attic spaces were setup as ocSPF-insulated unvented cathedralized attic (UCA) roof assemblies. Again, GWB was installed (taped and painted) on the underside of the bottom truss chords to create the ceiling finis. No poly vapour barrier was installed in these assemblies. Instead, the GWB was sealed to create the air barrier system (i.e. to isolate the attic from the room below). The top of the Roofs 2 and 3 were finished in a manner similar to Roof 1: the roofs were sheathed with 13 mm (0.5 in.) OSB, this was covered with #15 felt underlay then asphalt composite shingles were installed as the roofing. Roughly 250 mm (10 in.) of ocSPF insulation was applied directly to the underside of the OSB sheathing. The ocSPF insulation was carried down onto the GWB to seal the bottom edge of the assembly and prevent any air leakage at the eave / soffit.

Figure 13 and Figure 14 show the construction and instrumentation of Roofs 2 and 3, the two ocSPF-insulated unvented cathedralized attic roof assemblies. The only difference between Roofs 2 and 3 is the application of 2 coats of latex paint on the underside of the ocSPF insulation in Roof 2. This was applied to assess the impact of applying an additional but modest vapour control layer.[2]

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[2] The latex paint vapour control layer was proposed as a method to reduce the rate of outward diffusion during the winter months.

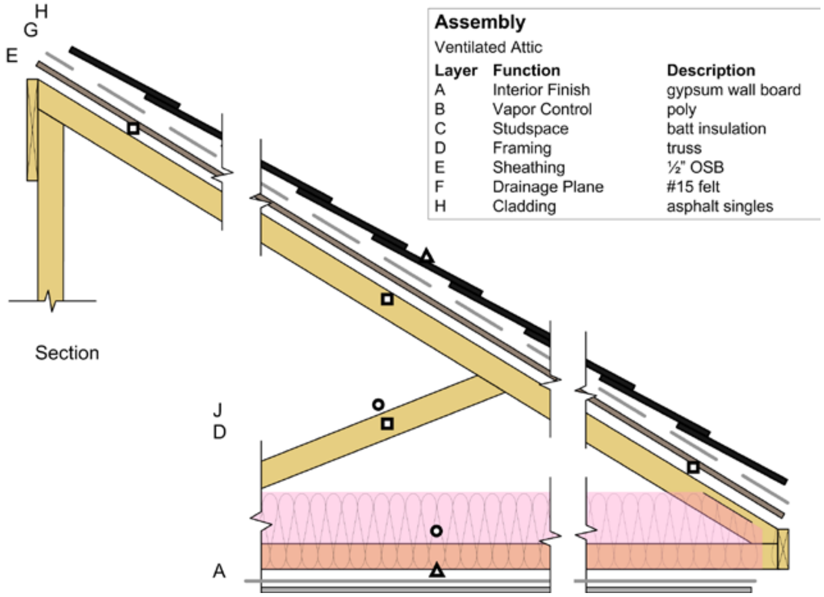

Figure 12 – Coquitlam Test Hut Roof Study, Roof 1 – Ventilated Attic

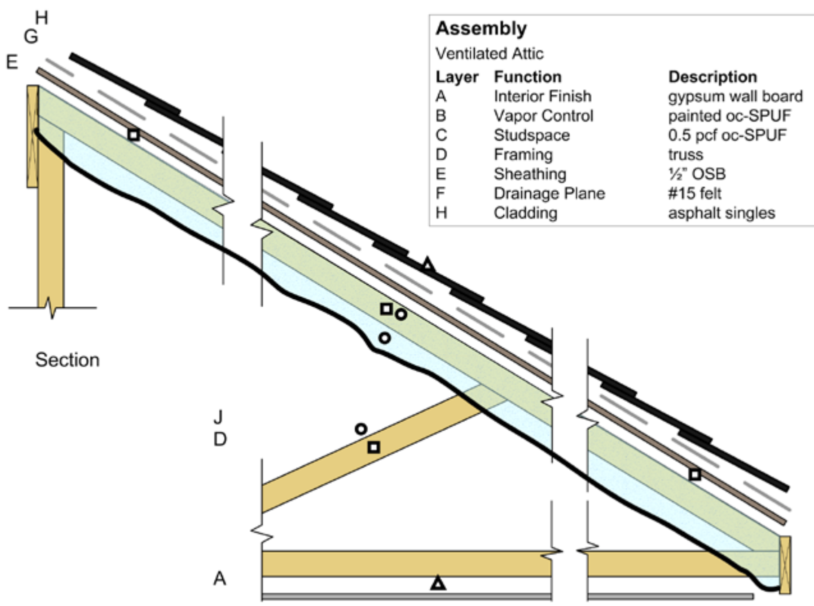

Figure 13 – Coquitlam Test Hut Roof Study, Roof 2 – ocSPF-Insulated Unvented Cathedarlized Attic with Latex Paint Vapour Control

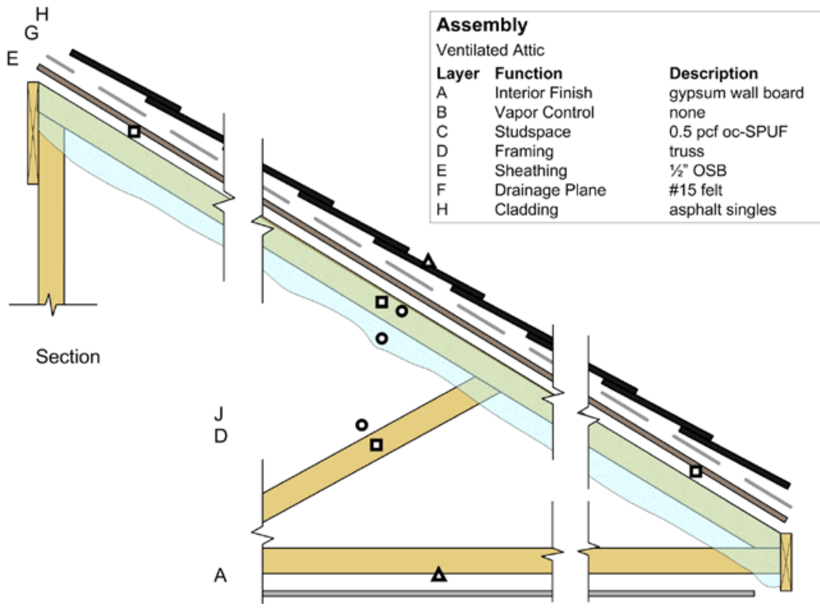

Figure 14 – Coquitlam Test Hut Roof Study, Roof 3 – ocSPF-Insulated Unvented Cathedarlized Attic

Monitoring equipment was also installed to measure and record indoor and outdoor temperature and relative humidity, wind speed and direction, rainfall, driving rain, and solar radiation on the horizontal and each wall orientation.

The Coquitlam Test Hut is outfitted with electric resistance heat, steam humidification (to increase indoor RH), and a ventilation system (to decrease indoor RH). No air conditioning was installed (as is common in residential buildings in Vancouver and the Lower Mainland). Readers are directed to Schumacher (2008) for more details regarding the monitoring setup.

The Coquitlam Hut Roof Study ran from Fall of 2005 through Summer of 2009. Nearly four full winters were included in the study period. Figure 15 shows the outdoor and indoor temperature and dewpoint conditions measured during the study period. In the conditioned space (the "room") wintertime temperatures were maintained at approximately 20°C (68°F) and dewpoint was maintained around 9°C (48°F).

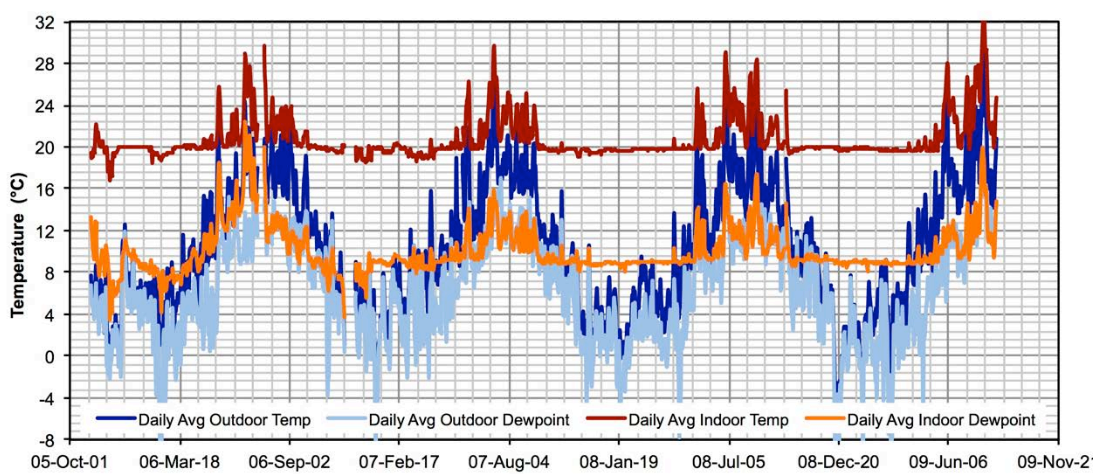

Figure 15 – Outdoor and Indoor Temperature and Dewpoint Recorded During the Coquitlam Hut Roof Study

Attic Dewpoint

Figure 16 shows compares the dewpoint temperatures measured in each of the three test attics. As expected, the dewpoint in the ventilated attic closely matches the outdoor dewpoint. In contrast but still as expected, the dewpoint measured in the two ocSPF-insulated unvented cathedralized attics is often higher than the outdoor dewpoint. During the winter the dewpoint in the ocSPF-insulated unvented cathedralized attics runs between 2 and 7°C (36 and 45°F), lower than the indoor dewpoint of approximately 9°C (48°F). This maybe the result of the vapour pressure gradient (i.e. drop) that exists as water vapour diffuses from the room, through the painted GWB ceiing, into the attic.

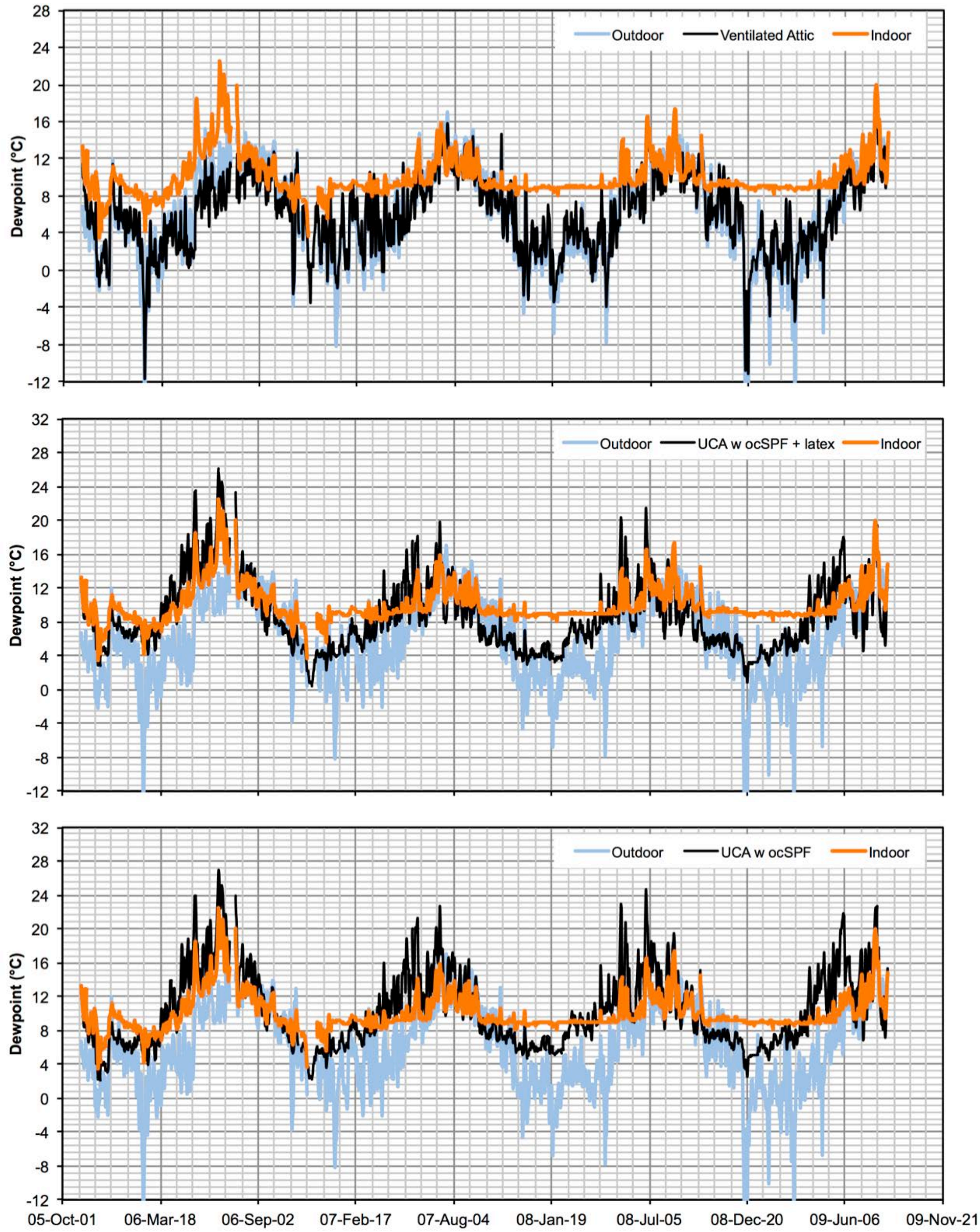

Figure 16 – Coquitlam Hut Indoor, Outdoor and Attic Dewpoint – Roof 1, Ventilated Attic (top); Roof 2, ocSPF UCA with latex Paint Vapour Control (mid); Roof 3, ocSPF UCA (bottom)

Roof Sheathing Temperature

Figure 17 compares the roof sheathing temperatures measured on the north-facing roof slope of each of the three test attics. The north-facing roof slopes receive less solar radiation, run lower roof sheathing temperatures, and experience higher relative humidity and moisture content than the south-facing roof slopes. There is a modest temperature difference between maximum and minimum roof sheathing temperatures recorded in the ventilated attic and those recorded in the two ocSPF-insulated unvented cathedralized attics.

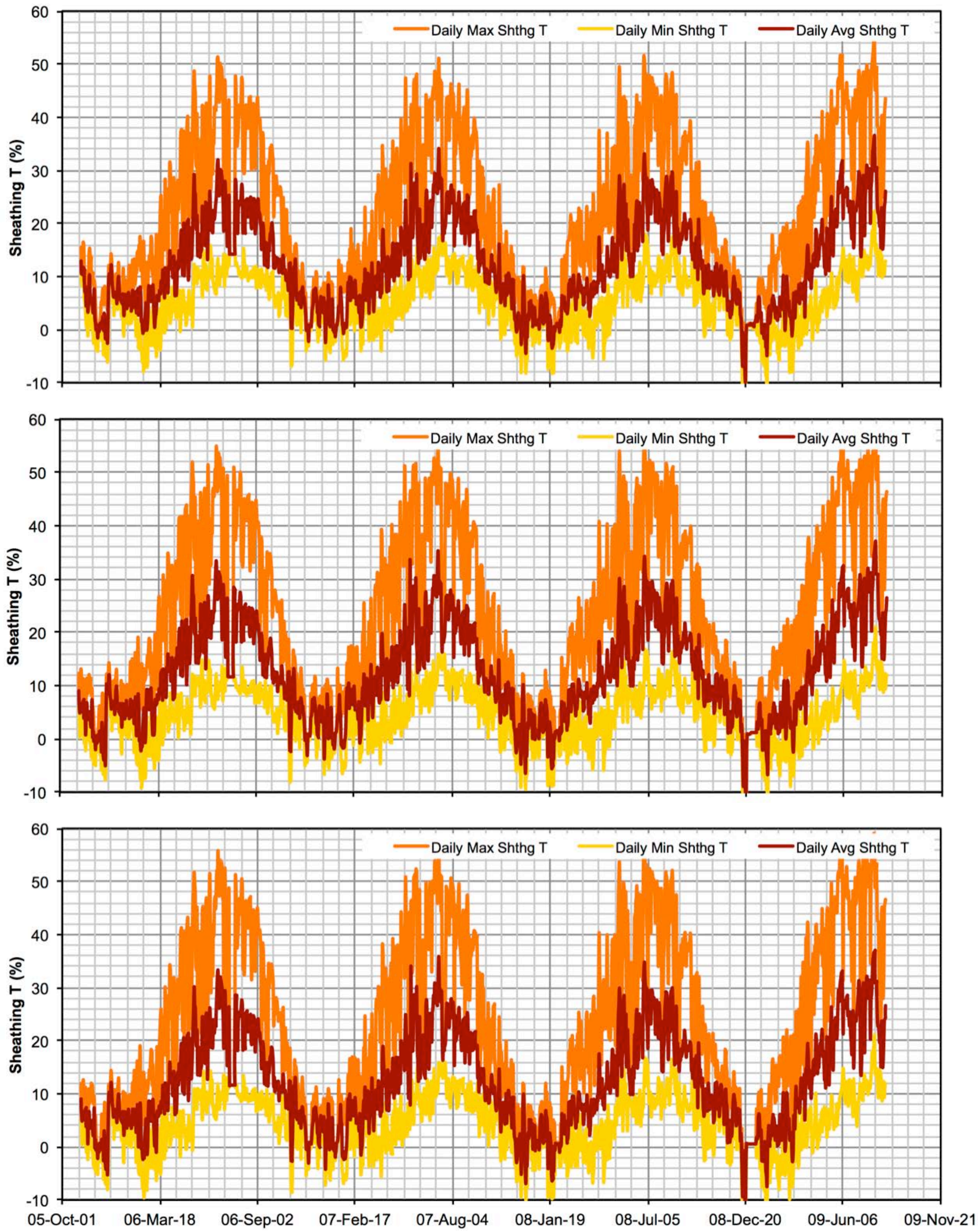

Figure 17 – Coquitlam Hut North-facing Roof Slope Sheathing Temperature – Roof 1, Ventilated Attic (top); Roof 2, ocSPF UCA with latex Paint Vapour Control (mid); Roof 3, ocSPF UCA (bottom)

Roof Sheathing Relative Humidity

Figure 18 compares the relative humidity at the roof sheathing on the north-facing roof slope of each of the three test attics. As expected both of the ocSPF-insulated unvented cathedralized roof assemblies experience a longer period of elevated (i.e. over 80% RH) relative humidity during the winter season. However, the unvented assemblies also exhibit less daily fluctuation. Through the summer and fall season the ventilated attic frequently experiences daily maximum relative humidity in excess of 80% RH. This might be caused by moisture deposition from high dewpoint ventilation air when the roof sheathing is cooled at night.

Higher initial RH in Roof 2 may be indicative of slower inward drying of built-in moisture, limited by the latex paint that was added as a vapour control layer on the indoor face of the ocSPF.

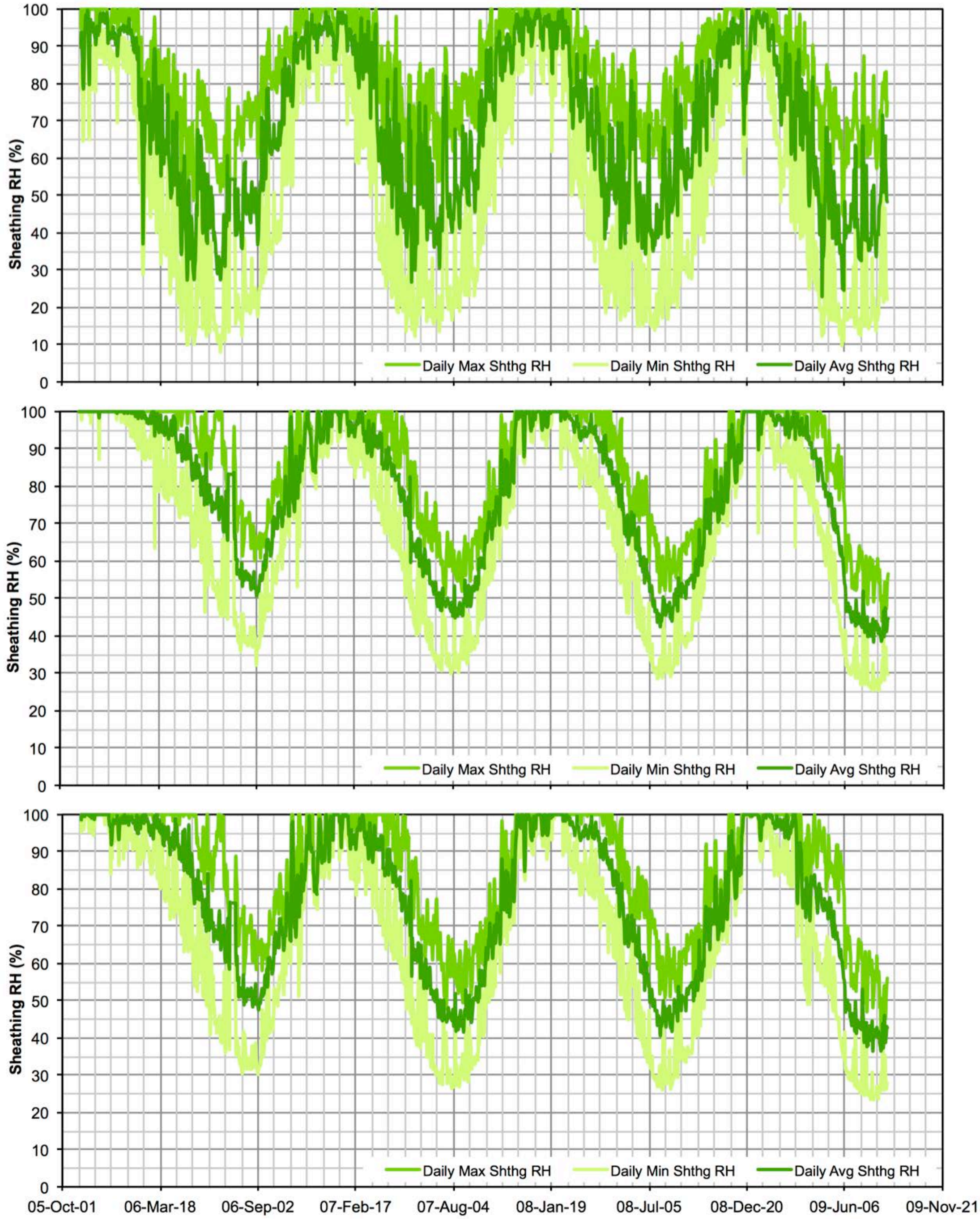

Figure 18 – Coquitlam Hut North-facing Roof Slope Sheathing Relative Humidity – Roof 1, Ventilated Attic (top); Roof 2, ocSPF UCA with latex Paint Vapour Control (mid); Roof 3, ocSPF UCA (bottom)

Mold index

Figure 19 shows the calculated mold index for the sheathing on the north-facing roof slope in each of the three test attics. The ocSPF-insulation in the unvented cathedralized attics assemblies limits the rate of inward drying of built-in moisture. The unvented cathedralized attic assemblies of the Coquitlam Hut exhibit a Ping-Pong moisture effect similar to that observed in the unvented cathedral ceiling roof assembly of the Dunbar-Southland House. The effect is evident over the first 4 years for Roof 2, with the latex paint vapour control layer. In contrast, Roof 3, without the latex paint, appears to dry our over the first 2 years. By year 4 Roof 3 exhibits a similar calculated mold index to Roof 1, the ventilated attic.

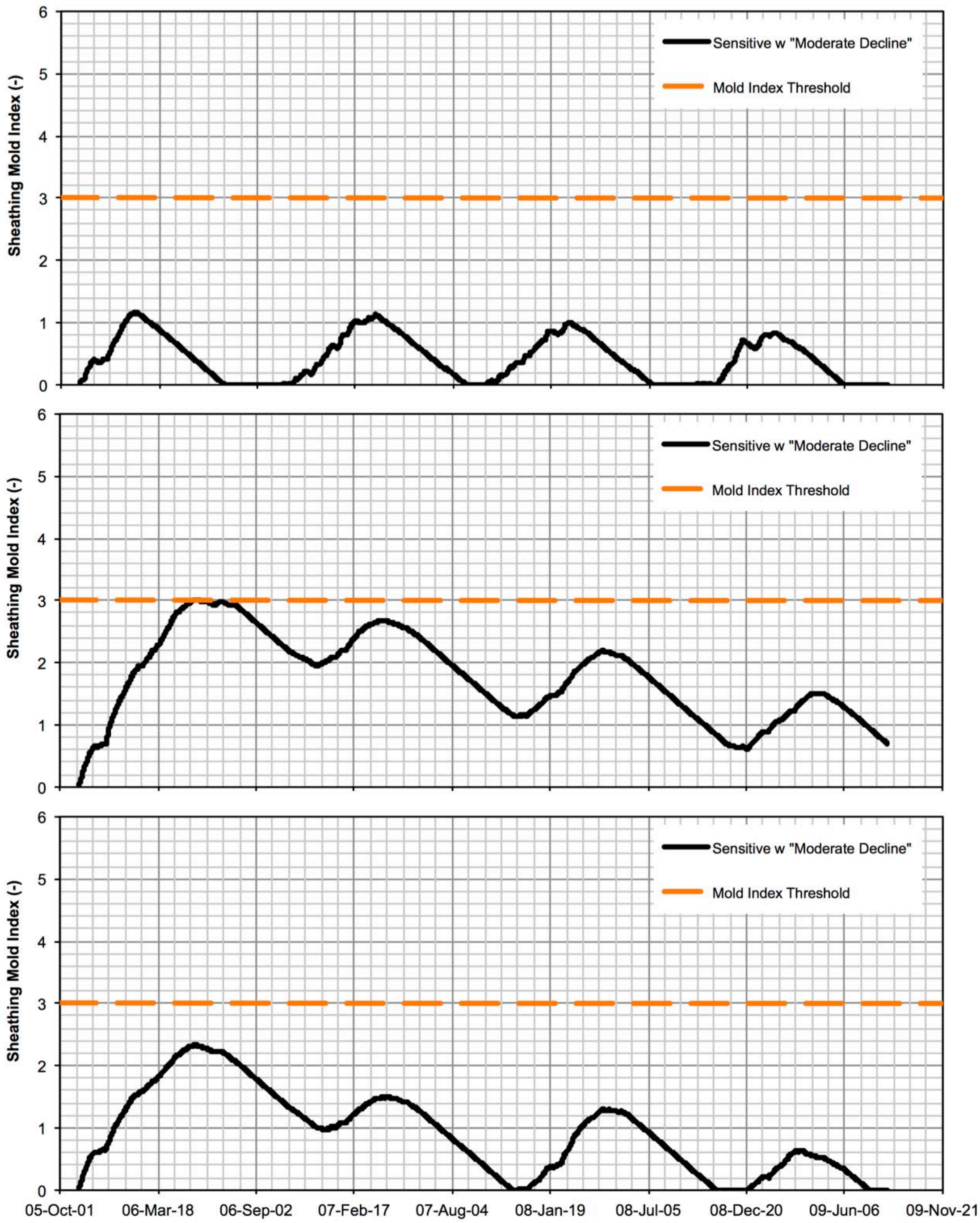

Figure 19 – Coquitlam Hut North-facing Roof Slope Sheathing Mold index – Roof 1, Ventilated Attic (top); Roof 2, ocSPF UCA with latex Paint Vapour Control (mid); Roof 3, ocSPF UCA (bottom)

9 Year Inspection Openings

The three test attics were continuously monitored for the first 4 years of Coquitlam Test Hut. Inspection openings were cut in the ocSPF roof insulation (of Roofs 2 and 3) at the end of the 1st full winter and at the end of the 4 years of monitoring. The ventilated attic was inspected at the same time. There was no visible mold in any of the test openings in Roofs 2 and 3, or on any of the visible roof sheathing in Roof 1. Furthermore, it took two hands to drive the pins of the moisture meter into the OSB roof sheathing (as it would new sheathing).

An additional (and new) set of inspection openings were made on May 5th of 2015, more than 9 years after the test roof assemblies were constructed. The timing of the investigation corresponds with the peak annual Mold index.

Roof 1, Ventilated Attic Roof Assembly

Figure 20 and Figure 21 show the OSB roof sheathing and truss chords on the north-facing slope of Roof 1, the ventilated attic roof assembly in May of 2015. After 9 years of operation and, at the peak of the annual Mold index, still no visible mold was identified on the visible OSB sheathing or the wood framing of the trusses. Protruding roofing nails were noticeably rusty.

At the time of the investigation the outdoor temperature was roughly 9°C (48°F), the outdoor dewpoint was approximately 7°C (45°F), the attic temperature was 20°C (68°F), and the attic dewpoint was 9.5°C (49°F). The sky was overcast and the roof sheathing temperature was 14-16°C (47-61°F). The sheathing moisture content ranged from 6.5% on the South-facing slope to 9% on the North-facing slope (Figure 22 and Figure 23)

Roof 2, ocSPF-Insulated Unvented Cathedralized Attic Roof Assembly with Latex Paint Vapour Control

Figure 20Figure 24 shows an investigator pushing the pin-type moisture meter into the OSB roof sheathing the north-facing slope of Roof 2, the ocSPF-insulated unvented cathedralized attic roof assembly with latex paint vapour control. After 9 years of operation the sheathing was still stiff and sound; two hands were needed to push the pins into the sheathing. Once in, the sheathing easily supported the weight of the moisture meter (Figure 25). Still no visible mold was identified OSB sheathing in the inspection openings.

At the time of the investigation the attic temperature in Roof 2 was 22°C (72°F), and the attic dewpoint was 15°C (59°F). Under the overcast sky the roof sheathing temperature was 18-22°C (64-72°F). The sheathing moisture content ranged from 9% on the South-facing slope to 13% on the North-facing slope (Figure 26 and Figure 27).

Roof 3, ocSPF-Insulated Unvented Cathedralized Attic Roof Assembly

Figure 28 shows an investigator making an investigation opening in the ocSPF on the north-facing slope of Roof 3, the ocSPF-insulated unvented cathedralized attic roof assembly. Figure 29 shows the two lifts of foam that were applied to achieve the 250 mm (10 in.) total thickness. Again the roofing nails were noticeably rusty, but no visible mold was identified OSB sheathing in the inspection openings.

At the time of the investigation the attic temperature in Roof 3 was also around 22°C (72°F). The attic dewpoint was 16°C (61°F). Under the overcast sky the roof sheathing temperature was 18-21°C (64-70°F). The sheathing moisture content ranged from just under 9% on the South-facing slope to a little over 13% on the North-facing slope (Figure 30 and Figure 31).

Figure 20 – Coquitlam Hut 9 yr Photo –Roof 1, Ventilated Attic – Sheathing at Ridge

Figure 21 – Coquitlam Hut 9 yr Photo – Roof 1, Ventilated Attic – Sheathing at Eave on North-facing Slope

Figure 22 – Coquitlam Hut 9 yr Photo – Roof 1, Ventilated Attic – Sheathing MC on South-facing Slope

Figure 23 – Coquitlam Hut 9 yr Photo – Roof 1, Ventilated Attic – Sheathing MC on North-facing Slope

Figure 24 – Coquitlam Hut 9 yr Photo – Roof 2, ocSPF-Insulated UCA with Latex Paint – Pushing Moisture Meter into OSB Sheathing

Figure 25 – Coquitlam Hut 9 yr Photo – Roof 2, ocSPF-Insulated UCA with Latex Paint – Moisture Meter Hangs in OSB Sheathing

Figure 26 – Coquitlam Hut 9 yr Photo – Roof 2, ocSPF-Insulated UCA with Latex Paint – Moisture Content on South-facing Slope

Figure 27 – Coquitlam Hut 9 yr Photo – Roof 2, ocSPF-Insulated UCA with Latex Paint – Moisture Content on North-facing Slope

Figure 28 – Coquitlam Hut 9 yr Photo – Roof 3, ocSPF-Insulated UCA without Latex – Creating Inspection Opening

Figure 29 – Coquitlam Hut 9 yr Photo – Roof 3, ocSPF-Insulated UCA without Latex – 2 Lifts of Foam Visible

Figure 30 – Coquitlam Hut 9 yr Photo – Roof 3, ocSPF-Insulated UCA without Latex – Moisture Content on South-facing Slope

Figure 31 – Coquitlam Hut 9 yr Photo – Roof 3, ocSPF-Insulated UCA without Latex – Moisture Content on North-facing Slope

4. Survey of ocSPF-Insulated Unvented Roofs in Vancouver and the Lower Mainland

BSCI staff queried building scientists and consultants in Vancouver and the Lower Mainland in an attempt to find ocSPF unvented roofs (either cathedralized attics or cathedral ceilings) that had reported moisture problems. However, our contacts reported that they only knew of ocSPF-insulated unvented roofs that had problems related to bulk water penetration (i.e. leakage of rain or melt water).

Icynene volunteered three buildings with owners that were willing to allow us to make investigative openings to into their ocSPF-insulated unvented roof assemblies. All three sites were visited on a morning in early May of 2015. The sky was overcast, the outdoor temperature was approximately 6°C (43°F) and the outdoor dewpoint was 5°C (41°F).

Langley Workshop

The Langley Workshop serves as an equipment and tool repair and maintenance shop for a local contractor. Figure 32 shows the workshop from the front. The building is decades old and the age of the wood is evident in its dark colour. Roughly 5 years ago ocSPF insulation applied to create a cathedralized unvented attic. The resulting roof assembly doesn't include any vapour control layers to limit outward diffusion during cold weather.

Large openings exist in the ceiling so the air in the attic has the same properties as the air in the workshop below. Furthermore, the building appears to be very leaky so it should be expected to track outdoor dewpoint conditions. However, there are significant sources of indoor moisture associated with some of the processes employed in the workshop.

On the morning of the visit the temperature in the attic was roughly 15°C (59°F) and the relative humidity was 50% so the dewpoint equal to outdoor dewpoint. The exposed wood framing elements (collar ties) registered moisture content of 10.5%.

Inspection openings were made at two locations on the north-facing slope and two locations on the south facing slope (Figure 34). No visible mold were observed on the exposed plywood sheathing (Figure 35). However, the plywood sheathing was dark with age in a manner similar to the wood framing. On the north-facing slope the moisture content of the sheathing was around 12% while it was just under 7% on the south-facing slope (Figure 36 and Figure 37).

Figure 32 – Langley Workshop

Figure 33 – Langley Workshop – Moisture Content of Exposed Wood Framing

Figure 34 – Langley Workshop – Cutting an Investigation Opening in the ocSPF

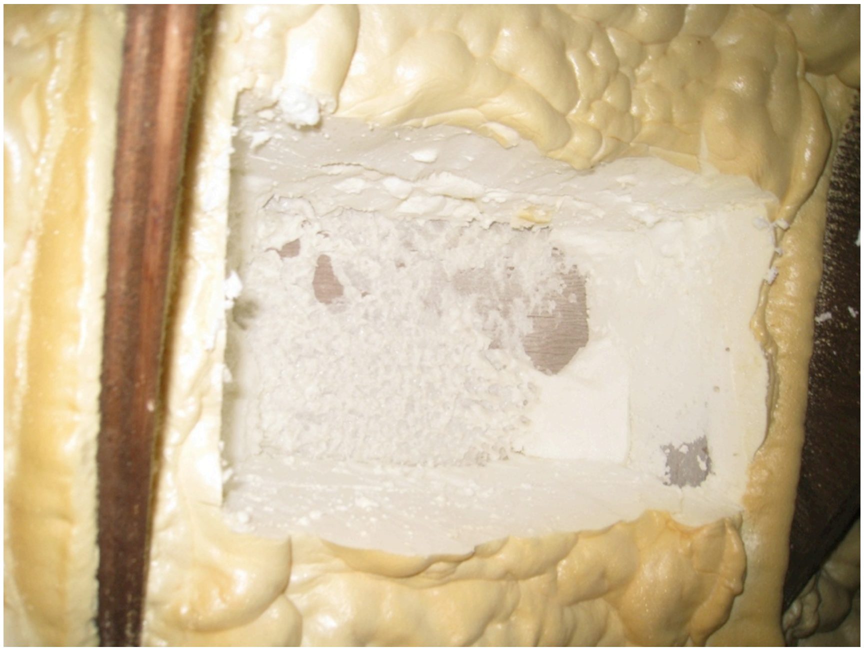

Figure 35 – Langley Workshop – Investigation Opening on North-facing Slope

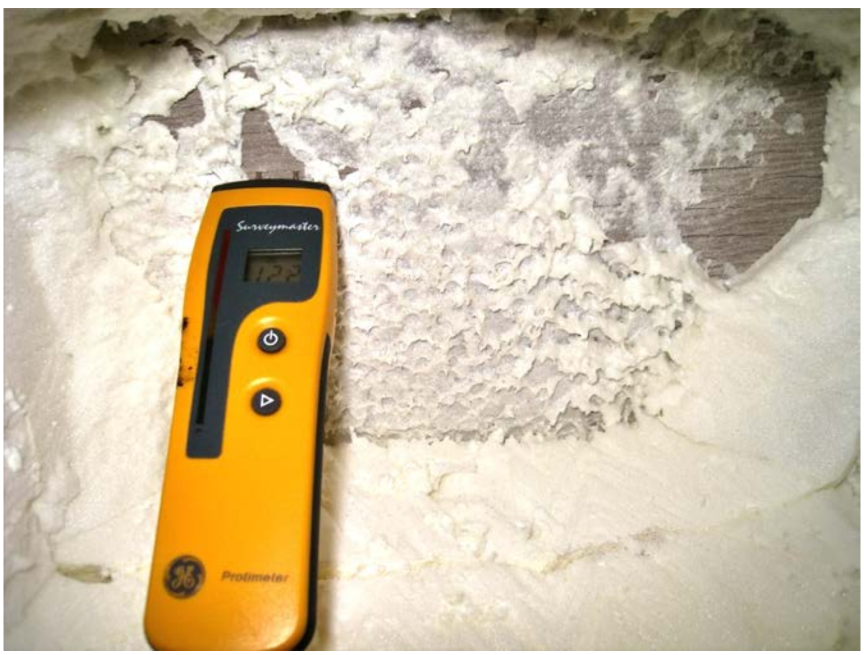

Figure 36 – Langley Workshop – Moisture Content Measured in Sheathing on North-facing Slope

Figure 37 – Langley Workshop – Moisture Content Measured in Sheathing on South-facing Slope

Langley Trailer Home

The Langley Trailer Home was renovated approximately 3 years ago (Figure 38 and Figure 39). The walls and roof of the structure were insulated with 100-200 mm (4-6 in.) of ocSPF insulation. The roof assembly has a very low slope so the renovation produced a very flat ocSPF-insulated cathedral ceiling roof assembly. The roof assembly does not include a polyethylene vapour barrier however, the painted GWB ceiling may provide some control of outward vapour diffusion during cold weather.

The renovation resulted in a very airtight structure that was without an operating ventilation system. Everyone noted the feeling of high humidity on entering the building. The indoor temperature was almost 19°C (68°F) and the relative humidity was almost 70% so the indoor dewpoint was over 13°C (54°F), well above recommended levels for early spring (Figure 40).

Two inspection openings were made: the first in the utility room off the kitchen and a second in the bedroom at the other side of the house. The surface of the plywood sheathing felt damp but there was no visible mold in either of the inspection openings. Sheathing moisture contents of 16.3 and 15% were measured in the two inspection openings.

While we did not note any visible signs of mold, we strongly recommend against operating with an indoor RH of 70% in the climate of Vancouver and the Lower Mainland. In this climate ventilation systems should be designed, installed and operated to maintain wintertime indoor humidity below 40% RH.

Figure 38 – Langley Trailer Home – Outside View

Figure 39 – Langley Trailer Home – Renovated Kitchen

Figure 40 – Langley Trailer Home – Indoor Temperature (left) and High Relative Humidity (right)

Figure 41 – Langley Trailer Home – Inspection Opening 1 – Utility Room

Figure 42 – Langley Trailer Home – Inspection Opening 1 – Sheathing Moisture Content

Figure 43 – Langley Trailer Home – Inspection Opening 2 – Bedroom

Figure 44 – Langley Trailer Home – Inspection Opening 2 – Sheathing Moisture Content

Langley Hobby Garage

The Langley Hobby Garage is constructed and finish in a manner closer to that of a home than a stand alone garage. The owner uses the structure to protect, house, and work on his collector cars. The building employs an ocSPF-insulated unvented chathedral ceiling with scissor trusses. The roof assembly does not use a polyethylene vapour barrier but the ceiling is finished with painted GWB.

The Langley Hobby Garage had a much more reasonable indoor dewpoint than the Trailer Home. The indoor temperature was 16.5°C (62°F) and the relative humidity was approximately 50% so there was a 6°C (43°F) dewpoint in the Hobby Garage.

A moisture content of 10% was measured in the plywood roof sheathing near the ridge.

Figure 45 – Langley Hobby Garage – Outside View

Figure 46 – Langley Hobby Garage – Inside View

Figure 47 – Langley Hobby Garage – Scissor Trusses and ocSPF Insulation

Figure 48 – Langley Hobby Garage – Moisture Content of Plywood Roof Sheathing

5. Summary and Takeaways

This document provides a summary of research work that BSCI has done to assess the moisture performance of ocSPF-insulated unvented roof assemblies in the climate of Vancouver and the Lower Mainland of BC.

The components and functions of conventional ventilated attic and ventilated cathedral ceiling roof assemblies are discussed and contrasted with those of unvented cathedralized attics (UCAs) and unvented cathedral ceilings (UCCs). In the climate of Vancouver and the Lower Mainland of BC there are several compelling arguments for eliminating roof vents and switching to unvented roof assemblies:

- ***Unvented assemblies prevent the entry of damp coastal air****.* In coastal areas, ventilated attic roof assemblies allow damp coastal air to bring moisture into the attic. Moist outdoor (ventilation) air creates a problem in the climate of Vancouver and the Lower Mainland where there are long cloutdy periods with little solar heating. In this climate roof sheathing and framing materials experience higher long-term moisture content levels and increased incidence of moisture problems such as mold.
- ***Unvented assemblies prevent entry of wind-driven rain*****.** Many parts of Vancouver and the Lower Mainland experience more than 1000 of hours of light rainfall per year. Rain drops are small and easily carried into roof vent openings where they deposit on insulation, roof sheathing and framing materials.

BSCI conducted two major research projects on ocSPF-insulated unvented roof assemblies in the Vancouver area: the Dunbar-Southland House and the Coquitlam Hut Roof Study. In both projects ocSPF-insulated unvented roof assemblies were constructed without the use of polyethylene vapour barriers. In both projects wintertime moisture performance was of particular interest and instrumentation was installed to assess the moisture balance in the roof assemblies as wintertime outward vapour diffusion caused an accumulation of moisture in the roof sheathing. Investigative openings were made to permit visual inspection of the roof sheathing and framing materials. The BSCI research programs identified several important trends:

- ***The ventilated attic test roof assembly experienced high moisture levels during warmer periods, when there a greater potential for mold growth.*** High relative humidity was recorded in the ventilated attic of the Coquitlam Test Hut, often when temperatures were higher and more likely to facilitate the growth of mold. It is likely that the moisture was introduced by moist ventilation air.
- ***The unvented test roof assemblies experienced high moisture levels during colder periods, when there was a lower potential for mold growth.*** High winter and spring sheathing moisture content and relative humidity levels were recorded in all ocSPF-insulated unvented roof assemblies included in BSCI's studies.
- ***No visible mold could be seen in any of the ocSPF unvented test roof assemblies.*** After 9 years of operation the roofs at the Coquitlam Test Hut still exhibited no signs of visible mold and the assemblies appear to provide acceptable service.
- ***The predicted Mold Index for all of the test roof assemblies remained below the threshold value of 3, above which visible mold is likely to be found.*** Mold Index analyses, prepared using measured data from the studies, agree with the field observations of no visible mold.

When constructing ocSPF-insulated roof assemblies in the climate of Vancouver an the Lower Mainland builders should:

- ***Minimize rain exposure during construction to prevent built-in moisture in unvented roof assemblies***. Built-in moisture can take several years to dry out of an ocSPF-insulated unvented roof assembly.
- ***Identify and execute an air barrier system.*** Where ocSPF-insulated unvented roof assemblies do not use poly air / vapour barriers, it is important to ensure a continuous air barrier system is provided. For example, the air barrier system may consist of ocSPF with sealant between wood-to-wood connections (structural members). Similarly, the air barrier system could be created using air-drywall approach or other accepted methods. The air barrier system should be identified in construction documents, designed, detailed, built and commissioned.
- ***Control indoor humidity levels.*** A ventilation system (or other means) should be provided, commissioned and operated to maintain indoor humidity levels below 40% during the winter months (October through April). Building occupants should be educated in the need for and proper operation of the humidity control system.

6. References

Ojanen, T., H. Viitanen, R. Peuhkuri, K. Lähdesmäki, J. Vinha, and K. Salminen. “Mould growth modeling of building structures using sensitivity classes of materials”. *Thermal Performance of the Exterior Envelopes of Whole Buildings XI*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2010

Rickets, L., Finch, G. “Mold in Vented Wood-Frame Roofs in the Coastal Pacific Northwest”, *RDH Technical Bulletin No. 010*, Vancouber BC, 2015.

Schumacher, C.J., “Hygrothermal Performance of Insulated, Sloped, Wood-Framed Roof Assemblies”. University of Waterloo, Waterloo ON, 2008

Schumacher, C.J., Reeves, E. “Field Performance of an Unvented Cathedral Ceiling (UCC) in Vancouver”. *Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference*, Clearwater, Dec 2007.