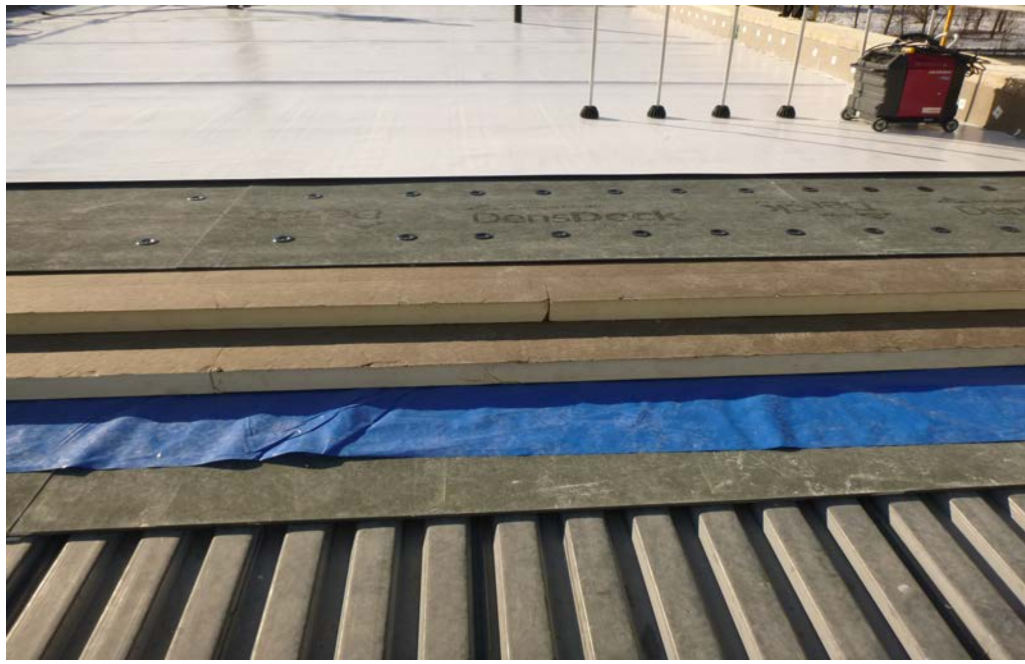
# Comparing Condensation Potential in Conventional and Hybrid Roof Assemblies:

## A Case Study

By David Wach, M.A.Sc., Engineer-in-Training, & Vladimir Maleev, M.Eng., P.Eng., BSSO, Associate, Engineering Link Inc.




*Layers of a typical conventional roof.*

When a designer is considering options during a low-slope roofing project, in most cases, the first decision is the assembly type. The choice is typically limited to two options: conventional roof assemblies, or protected membrane roof assemblies.

In conventional assemblies, the roof membrane is found at the top of the assembly, above the insulation, and is considered exposed to the elements. If the roof membrane is not made of a UV stable material, it is protected from UV by a surfacing layer. The surfacing can include granules, pea gravel, pavers, metal, or liquid-applied coatings. The roof assembly layers are attached to the immediate layer underneath, or to the deck, through mechanical fastening or adhesives.

Protected membrane roof assemblies are also known as inverted roof assemblies. In a typical inverted configuration, the roof membrane is located at the level of the structural deck or deck sheathing. As such, it is protected from the elements by other layers of the roof assembly, including thermal insulation. The roof membrane is protected from UV exposure and from thermally induced dimensional stress. Roof assembly layers above the roof membrane are, by and large, loose laid and resist wind uplift by a weighted ballast.

In general, there are a few advantages of protected membrane assemblies when compared with conventional assemblies. If correctly installed and maintained, protected membrane assemblies can have a longer lifespan compared to conventional assemblies and can also be expected to have a lower incidence of leaks over the entire lifespan of the roof system.

For a low-slope roof system to operate most effectively, slope to drains is required. The rule of thumb is two per cent slope at minimum for asphaltic-based conventional roof systems.[1] Ponding of water, even if protected from UV by the layers above the membrane, can be detrimental to the durability of certain roof membranes. Protected membrane roof assemblies are often installed on decks that are structurally sloped. Conventional roof assemblies can also be installed on structurally sloped decks, but in many instances, they incorporate the slope within the assembly itself in the form of tapered insulation.

During the design review process for a new construction project in the Greater Toronto Area, roofing was discussed, and the design team understood the benefits of a protected membrane roof. However, earlier in the project, a conventional roof assembly with tapered insulation had been specified and a flat structural steel deck was built.

At this stage, the question was whether it was still possible to install a roof assembly that provided the benefits of a protected membrane roof. The team ruled out switching to a protected membrane system, as it was not practical to provide the minimum amount of slope in the structure. Positive drainage and good roofing practice were required by the contract documents.

The team considered a "hybrid" roof assembly that combined a conventional roof assembly, including tapered insulation, with a layer of insulation (and other layers) on top of the conventional assembly.

Could a problem be created by installing this hybrid roof assembly in our heating climate? Consideration was given to the hygrothermal performance of the proposed hybrid roof assembly, taking into account that the roof membrane in a hybrid configuration would be kept warmer during

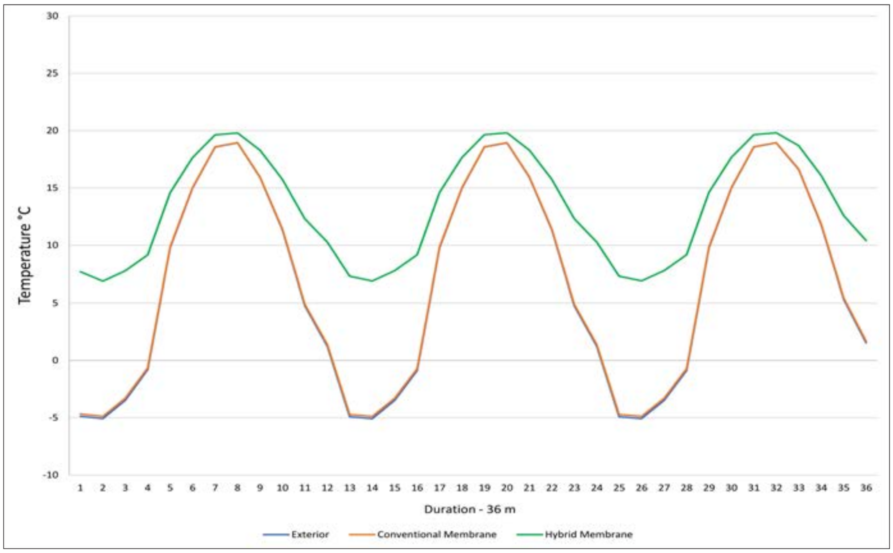



*Figure 1. Simulated temperature data.*

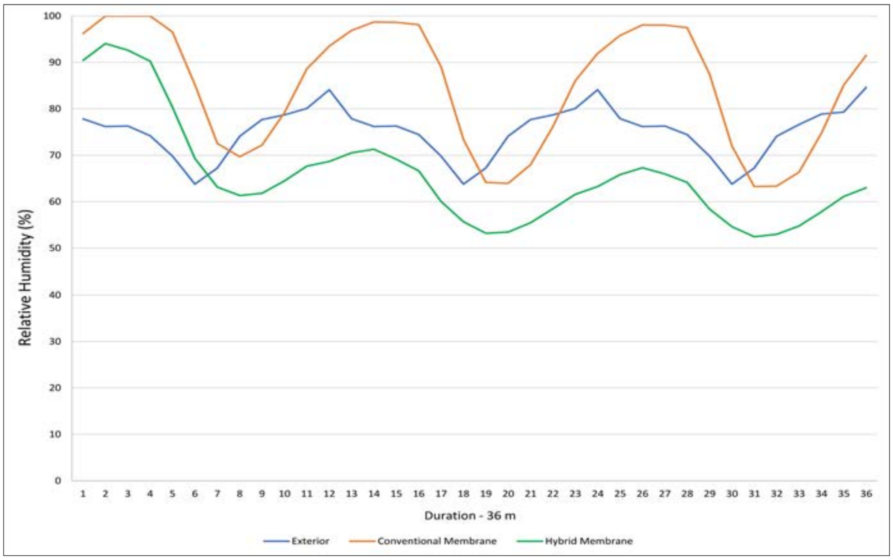



*Figure 2. Simulated relative humidity data.*

heating seasons by the presence of thermal insulation over the roof membrane when compared to a conventional configuration but would be cooler than a protected roof membrane with the same total amount of insulation. Clearly, the heat transfer and moisture characteristics of the hybrid assembly would be different than the two traditional options for low-slope roofs.

## CONDENSATION POTENTIAL IN CONVENTIONAL ROOF ASSEMBLIES

In the past, low-slope roofs were made of dark materials, including pitch and bitumen, which readily absorbed longwave radiation from the sun. On sunny days, during both winter and summer, the temperature of the dark membrane could be up to 80°C as it absorbed solar radiation, increasing the temperature of the roof assembly and any moisture within it. The heating caused a vapour pressure gradient, driving the vapour down to the interior space. The absence of a vapour retarder at the deck was tolerated because of solar vapour control.[2]

The introduction of light coloured, reflective roofs, often referred to as "cool roofs," introduced moisture problems in some assemblies where an effective vapour retarder did not exist. The light colour / reflectivity of the roof membrane resulted in a reduced amount of solar heating of the roof assembly. The reduced absorption of solar radiation and resulting lower temperature of the roof assembly was desirable from an energy perspective, but solar control of embedded moisture was reduced. In some cases, moisture problems from condensation developed, leading to deterioration of the roof assembly and structure.[3]

Modern, conventional roof assemblies in heating climates that are installed in low-slope roof systems often contain two vapour barriers that sandwich insulation and other roof system layers. Building codes in Canada require that an air barrier and vapour retarder (AB/VR) be provided in all building envelope assemblies, including roofs. The roof membrane acts as a second vapour retarder, as it's usually made of materials that have a low vapour permeability.

During heating seasons, the underside of the roof membrane in a conventional roof system can be cool if the exterior air temperature is cool. If warm, moist air exists within the roof assembly between the two vapour retarders, and it may condense into liquid water as it contacts materials with a temperature below the dew point of the air that contacts it.

If an AB/VR exists, how could moisture end up in the roof assembly? The mechanism could be bulk air movement or vapour diffusion despite the AB/VR. Poor detailing or poor installation of the air and vapour control layer tie-ins with adjacent building envelope assemblies and around penetrations can cause discontinuity in the control layers. Of course, moisture can also enter the roof assembly through breaches in the membrane (leaks) or can be embedded in the roof assembly from construction. As the two vapour retarders exist, once the liquid water is present, it can have a difficult time drying, as vapour diffusion potential is greatly reduced.

With the hybrid type roof assembly, the membrane is kept at a temperature closer to the interior space than the exterior air when compared to the membrane in a conventional roof assembly. Theoretically, the AB/VR should keep moisture out and the exterior insulation will keep the membrane relatively warm. The membrane is protected from solar radiation. But if moisture does get into the roof through poor detailing, installation, or leaks over time, how will the roof perform?

To confirm that a moisture problem would not be created by the hybrid assembly, and to assess its hygrothermal response under load, a study was undertaken to analyze the moisture response of the assembly over time in a southern Ontario climate.

## HYGROTHERMAL SIMULATIONS AND DISCUSSION

WUFI Pro 6 modelling software is a one-dimensional hygrothermal analysis program that performs simulations of coupled heat and moisture transfer across user-defined building envelope assemblies. Simulations to compare the performance of the hybrid roof assembly to the conventional roof assembly were performed.

The simulations were carried out over three years in order to evaluate the long-term hygrothermal performance of the roof assemblies. Exterior conditions were as per the built-in Toronto Cold Weather Year climate file. Interior conditions were held constant at 21°C and 40 per cent RH. Rain exposure was as per ASHRAE 160.

The typical conventional roof assembly modelled included a two-ply modified bitumen roof membrane, asphaltic recovery board, 150 mm of rigid polyisocyanurate insulation, a self-adhered membrane acting as both an air barrier and vapour retarder, exterior grade gypsum board, and a metal deck. The hybrid assembly contained the same layers as the conventional assembly, with the addition of 125 mm of extruded polystyrene (XPS) insulation outboard of the roof membrane. Note, to be conservative for dew point analysis, the same thickness of polyisocyanurate insulation was included within the hybrid assembly as was in the conventional assembly. In practice, the hybrid roof assembly would be expected to have only tapered insulation below the membrane.

Figures 1 and 2 (on page 28) show monthly average temperature and relative humidity data over the three-year time period for the conventional roof assembly, the hybrid roof assembly, and the exterior. The relative humidity data within the roof assemblies was taken just under the membrane.

The temperature and relative humidity in the conventional roof vary with the exterior temperature. In Figure 1, the exterior temperature is difficult to see because the membrane temperature in the conventional assembly closely matches it. The hybrid roof has a much smaller temperature amplitude than the conventional roof, as it is thermally insulated from temperature fluctuations of the exterior air by the exterior insulation. As such, the roof membrane in the hybrid roof assembly is exposed to less thermally induced stress.

The analysis also showed that the hybrid assembly has lower peak and average relative humidity than the conventional roof. As a result, the conventional roof assembly retains more moisture over time than the hybrid roof assembly does. This leads to a higher risk of condensation below the conventional roof membrane in the winter when compared to the hybrid roof assembly. The analysis also suggests that the hybrid roof has better drying potential since the relative humidity seems to decrease at a faster rate.

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## CONSIDERATIONS AND LIMITATIONS

The hygrothermal analysis does not include for airflow through the assembly and assumes that the AB/VR in the assembly and the roof membrane are airtight. The AB/VR membrane layer over the sheathing and steel deck should be applied in an airtight manner around all penetrations and the roof perimeter. This helps prevent the flow of warm, moist, bulk air into the roof assembly from the interior space during heating seasons due to convection. Initial moisture within the assembly in modelling was as per program defaults for each material. All wetting and drying in the modelled scenario are accounted for by vapour diffusion through materials. In the situation presented, the thermal resistance (R-Value) of the insulation under the assembly was roughly balanced with the insulation above the assembly. Altering the ratio of insulation that is under and over will alter the hygrothermal performance of a roof, just as it would a wall.

## CONCLUSION

With both large and small projects, design changes can occur after construction begins. In the case that spurred the analysis presented here, the owner wanted to realize the benefits from protecting the roof membrane from thermal stress and solar exposure, while using an already constructed flat roof deck. The result was a hybrid roof assembly configuration.

The analysis shows that there can be alternatives to the two traditional options when choosing new or replacement roof assemblies for low-slope roofing. Locating the membrane between layers of insulation can provide benefits over conventional roof construction under certain conditions. When evaluating if this option will work, it is important to consider not only hygrothermal performance but other factors as well such as long-term durability, expected service life and ease of maintenance and repair.

During construction, all materials should be kept in a dry condition to ensure the roof assembly is installed with minimal residual moisture. It is not practical to avoid embedded moisture within construction materials, but all liquid water must be avoided. The analysis shows that if moisture does enter the assembly through bulk air movement, diffusion, or other means despite best efforts during construction, a hybrid roof assembly can perform better than a conventional roof assembly in a heating climate and may be an option for designers. ■

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*David Wach joined Engineering Link Inc. in 2015 and currently works in the firm's building envelope department, focusing on building envelope restoration and building science. David has gained extensive thermal and hygrothermal modelling experience through academic research and industry practice.*

*Vladimir Maleev joined Engineering Link as an associate in 2014 and brings more than 14 years of construction experience in various roles across multiple sectors. Vlad's expertise in building envelope systems comes from working on some of the largest new construction and restoration projects in Canada.*

### REFERENCES

1. Canadian Roofing Contractors Association, 1983, *Building Slopes on Existing Roofs*, https://roofingcanada.com/wp-content/uploads/2018/05/Volume-29-Building-Slopes-on-Existing-Roofs-.pdf
2. J. Lstiburek, 2016, *Doubling Down: How Come Double Vapour Barriers Work?*, https://buildingscience.com/documents/building-science-insights-newsletters/bsi-092-doubling-down%E2%80%94how-come-double-vapor-barriers
3. Phil Dregger, 2013, *"Cool" Roofs Cause Condensation – Fact or Fiction?*, http://rci-online.org/wp-content/uploads/2013-03-dregger.pdf