Enhancing Roofing Performance by Understanding the When and Where for Air and Vapor Control Layers

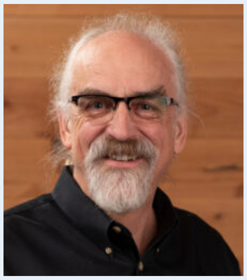
ABSTRACT

Roofs play a vital role in building performance, but their effectiveness hinges on proper moisture management. This session empowers designers, contractors, and building owners to make informed decisions regarding air- and vapor-control layers, crucial components affecting a building's energy efficiency, durability, and overall health. During this session, participants will explore the distinct functions of air barriers and vapor retarders, as well as appropriate applications in various climates and building types. Understanding the "when and where" of these control layers informs decisions that enhance a building's energy efficiency, durability, and overall health. This approach leads to the creation of cost-effective and long-lasting roof systems, ensuring a building's peak performance for years to come. The ever-evolving landscape of building design demands ever-evolving solutions. Roofs, once simple barriers against the elements, now play a much more intricate role. As buildings grow larger, environmental concerns heighten, and technology advances, our understanding of building science takes center stage. This session delves into the world of air- and vapor-control layers, the silent guardians of a building's key to moisture control, health, and energy efficiency.

LEARNING OBJECTIVES

- Explain the fundamental differences between air barriers and vapor retarders in terms of their material properties and vapor permeability.
- Discuss the impact of interior and exterior climate (temperature, humidity) on air and vapor control layer selection. The impact of the building's design interior humidity should also be discussed.
- Describe the requirements and differences of an air barrier and vapor retarder.
- Recognize proper placement strategies for air barriers and vapor retarders within various roof enclosure configurations and the influence of the interior and exterior climates.
- Describe how air and vapor control layers contribute to a building's energy efficiency, long-term building durability, and occupant health.

SPEAKER



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INTRODUCTION

The ever-evolving landscape of building design demands ever-evolving solutions. Roofs, once simple barriers against the elements, now play a much more intricate role. As buildings grow larger, environmental concerns heighten, and technology advances, our understanding of building science takes center stage. This article delves into the world of air- and vapor-control layers, the silent guardians of a building's key to moisture control, health, and energy efficiency. We will dissect the distinct functions of breathable membranes and non-permeable barriers, empowering designers and building owners to make informed decisions about their "when and where" in various climates and building types. By mastering the science behind these crucial components, you will gain the knowledge to craft cost-effective, long-lasting roofing systems that ensure peak building performance for years to come.

TRADITIONAL APPROACHES TO LOW-SLOPE ROOFING SYSTEMS

During the Industrial Revolution, as production increased, larger buildings were needed. The increase in footprint required the once-typical steep-slope roofing system to transition to a low-slope system. In the US, this transition took place in the early to mid-1800s. An example is the woolen mills in the upper East Coast regions transitioning from the original smaller building with steep-slope roofs to a large footprint requiring low-slope roofing (**Fig. 1** and **2**).

In the 1920s and 1930s, glass wool insulation began to be installed to prevent mold. However, this added insulation failed to control condensation. Teesdale, Rogers, and Rowley's publications on vapor barrier requirements in the late 1930s focused on moisture conditions in exterior materials during cold weather. This perspective was biased, emphasizing the importance of vapor transport, leaving out temperature and air-transported heat and moisture impacts.

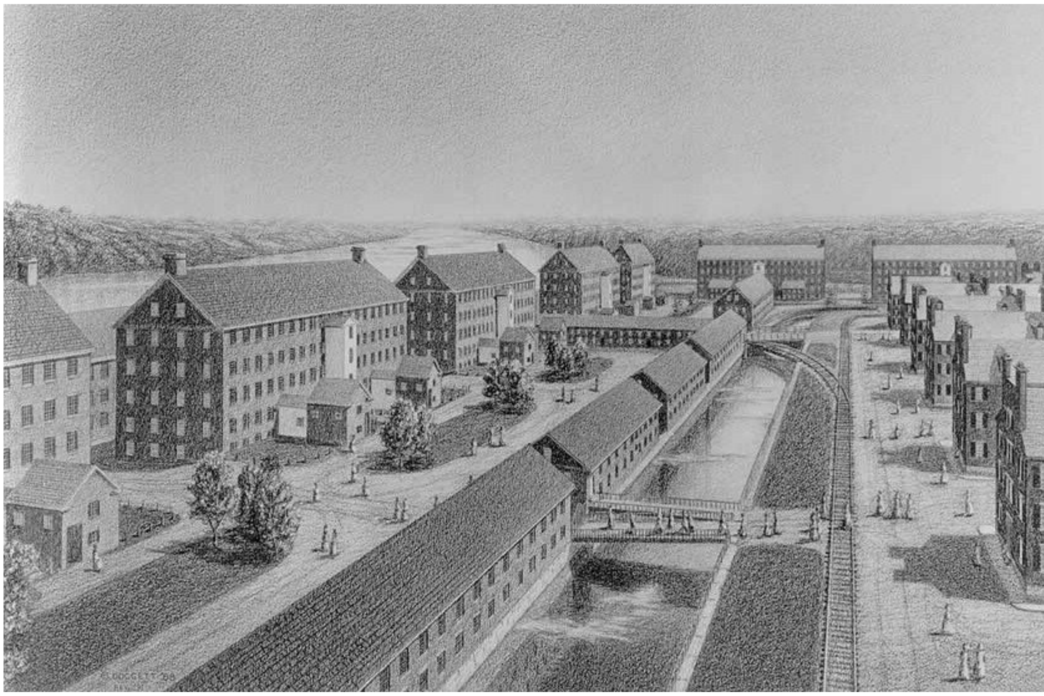

FIGURE 1. Drawing of the Boott Cotton Mills, 1850, by illustrator Kirk Doggett. *Courtesy of Lowell National Historical Park.*

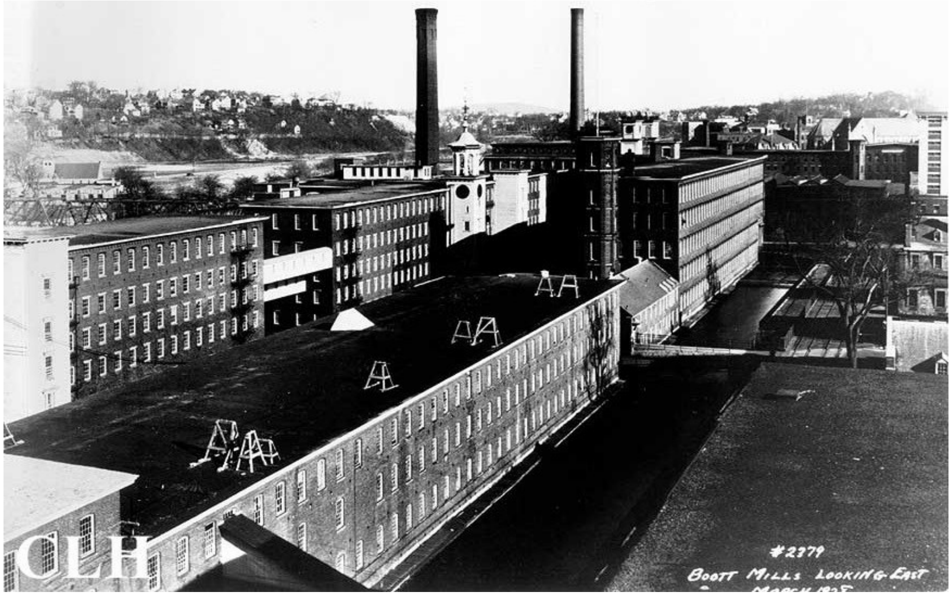

FIGURE 2. Photo of the Boott Cotton Mills, March 1928. *Courtesy of University of Massachusetts Lowell, Center for Lowell History.*

Their argument for the prevention of "condensation" focused solely on vapor transport and its inhibition as a recommendation. Though a vapor barrier can be an air barrier, they supported their argument with a flawed and misleading analogy of vapor diffusion as the major contributor for condensation. Those prescriptive recommendations later became code requirements. In 1942, the US Federal Housing Authority (FHA) Property Standard and Minimum Construction Requirements for Dwellings required 1-perm vapor restrictors. Building Officials and Code Administration (BOCA) model building codes published in 1950 also included vapor-restriction requirements. Low-slope roofing practices have historically focused on restricting vapor movement, ignoring airtightness, or confusing air barriers with vapor restrictors.

The oil embargo of the 1970s significantly increased energy costs for heating and cooling buildings. This, combined with growing concerns about energy conservation and indoor air quality, highlighted the impact of air exfiltration and infiltration. As a result, standards for air barriers were developed.

In 1985, the National Building Code of Canada (NBCC) incorporated air barrier requirements in Chapter 5, Environmental Separation. Later in 1995, the NBCC adopted 0.2 $L/s \cdot m^2$ @ 75 Pa (0.004 cfm/ft^2 @ 0.3 in. water gauge (w.g.), which is similar to the air leakage rate of ½ in. (12.7 mm) drywall. In the US, the Massachusetts energy code of 2001 adopted air barrier requirements based on the Canadian example noted above. The testing standard for air permeance followed with the 2001 approval of the ASTM International standard ASTM E2178, Standard Test Method for Air Permeance of Building Materials. In 2012, the International Energy Conservation Code (IECC) introduced the continuous air barrier requirement for new commercial construction.

UNDERSTANDING AIR BARRIERS AND VAPOR RETARDERS

Classifications for vapor barriers, now called vapor retarders, were implemented into codes with the 2006 *International Building Code* (IBC) supplement based upon vapor permeance, which is measured in perms. Class I is <0.1 perm, Class II is 0.1 to 1 perm, and Class III is 1 to 10 perms. Vapor diffusion, or vapor permeance, is defined as the amount of water vapor that moves through a given material. The weight of the water (grains), per time (hour), per a given area (ft^2) at a given pressure (1 in. of mercury) ($ng \cdot /s \cdot m^2 \cdot Pa$). The standard test for water vapor permeance, ASTM E96, now called *Standard Test Methods for Gravimetric Determination of Water Vapor Transmission Rate of Materials*, was adopted in 1941.

FIGURE 3. Cartoon showing the "seal tight, ventilate right" concept. *Courtesy of Jack Hébert, founder of the Cold Climate Housing Research Center.*

Though a vapor barrier can also be an air barrier, let us set vapor permeance aside for a moment. Contrary to the 1940s vapor barrier requirements, as early as the 1960s, A. G. Wilson published in the *Canadian Building Digest*[1] and Kirby Garden at the National Research Council of Canada (NRC)[2] described air leakage through the envelope as the major means by which water vapor moves to cold surfaces, causing condensation in buildings.

Later in 1977, Handegord at the Institute for Research Council of Canada concluded in a paper entitled "The Need for Improved Airtightness in Buildings"[3] "...suggested that air leakage wastes heat and is detrimental to the performance of a building". air leakage pathways. Later in his 1982 publication in Moisture Migration in Buildings[4] Handegord states, "Air leakage through the building envelope traditionally has been regarded as an acceptable means of ventilation, although it is a major cause of condensation problems in buildings...". During this period the principle of seal tight ventilate right was used to emphasize the importance of airtight envelopes. (**Fig. 3**) Handegord's papers provided the following additional contributions of air barriers:

- **Moisture control:** Airtightness helps manage moisture levels within a building by preventing condensation buildup, which can lead to mold growth and structural damage.
- **Energy savings:** Uncontrolled air infiltration through gaps and cracks in a building can lead to substantial heat loss or gain in warm climates, resulting in higher energy bills. Airtightness helps maintain a stable indoor temperature, reducing the need for excessive heating or cooling.
- **Improved indoor air quality:** By limiting air leakage, airtightness can prevent the entry of outdoor pollutants and allergens, enhancing indoor air quality for occupants.

The *International Residential Code* (IECC) an air barrier is defined as, "Materials assembled and joined together to provide a barrier to air leakage through the building envelope." According to the IECC the air barrier is a continuous system of materials that prevents or restricts air from passing through a building's envelope that surrounds the conditioned spaces.

A vapor retarder is designed to stop or slow vapor diffusion through solid materials, though it can also stop airflow if part of the continuous system of an air barrier. Let us compare vapor-transported moisture and air-transported moisture. **Figure 4** shows the difference in water

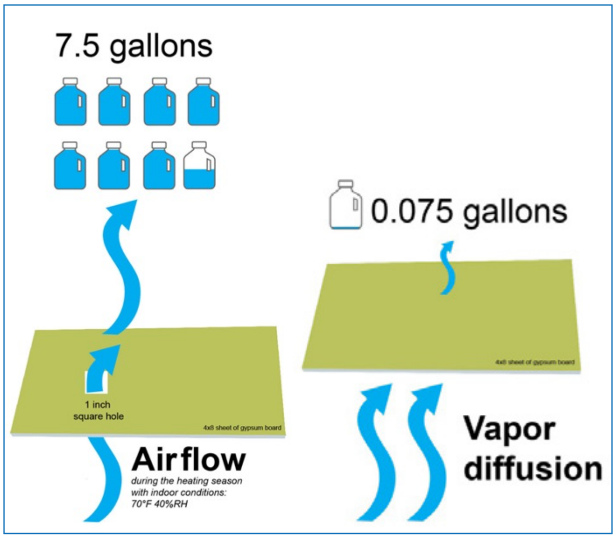

Figure 4. Comparison of moisture movement through airflow versus vapor diffusion.

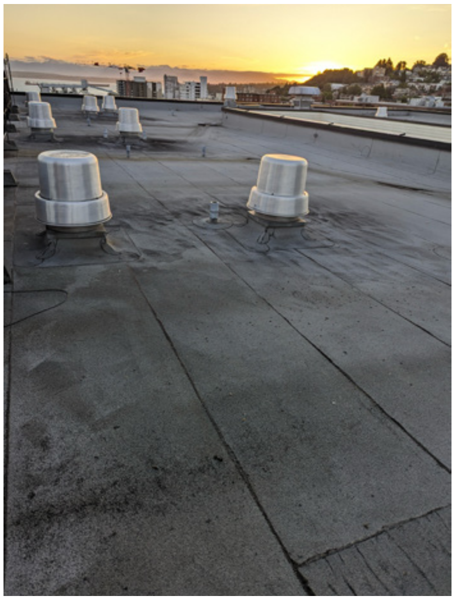

FIGURE 5. A modified bitumen roof.

vapor movement through a small hole compared to vapor diffusion through a solid material. Depending on the conditions, such as vapor permeance of the material, relative humidity, and vapor and air pressure differences, the amount of water transported through airflow is much more effective in moving moisture than vapor diffusion by 100 times.[5]

The Oak Ridge National Laboratory has an Energy Savings and Moisture Transfer Calculator that provides an estimate of the impact on energy use and moisture transfer based on air leakage based on climate locations and local energy source costs.[6] This calculator was funded through a joint effort of the Air Barrier Association of America, the US Department of Energy, and the Office of Science National Institute of Standards and Technology, providing a clearer understanding of the actual impact of air leakage in our buildings.

TECHNOLOGICAL ADVANCEMENTS IN LOW-SLOPE ROOFING

Since the introduction of low-slope roofing, material changes have occurred. With the discovery of asphalt, built-up layers were used in the late 1800s, developing into modified bitumen roofing introduced in the 1960s in Europe and in the early 1970s in the US. Modified bitumen roofing, a built-up roof system with plies of sheets and asphalt, is still in use (**Fig. 5**). With the development of synthetic polymers, roof membrane systems using these polymers were developed in the 1970s with ethylene propylene diene terpolymer (EPDM) and polyvinyl chloride (PVC) roof membranes. Later in the 1990s, thermoplastic polyolefin membranes (TPO) were introduced. Today membrane roofing has become the standard for new commercial low-slope construction.

BUILDING SCIENCE FUNDAMENTALS: HEAT, AIR, AND MOISTURE MANAGEMENT

Controlling heat, air, and moisture management is essential and is the core principle of building science that influences roofing system performance. These functions control the physical, chemical, and biological reactions of a roof system. They enclose the building, preventing water ingress and slowing heat transfer, controlling the indoor (conditioned) environment.

An overview of the low-slope roofing components is shown in **Fig. 6**. Typically, the roof covering, a single membrane, provides weather protection, stopping liquid moisture ingress. The insulation stops heat flow (conduction). The amount or R-value is dependent on the climate zone of the building's location environment. The air barrier stops airflow and is critical in stopping convective heat transfer and moisture movement in the air. In long-winter climate zones or when interior relative humidity levels are high, the air barrier may also need to control vapor flow.

Climate zones, first established in 2004 in the IBC, were put into a standardized climate zone map (**Fig. 7**). Relative to each climate zone, the IBC specifies how much insulation is required. As energy codes tightened, there were increases in the amount of required insulation. These climate zones also provide recommendations for vapor retarder classifications, though they are predominantly applied to walls with little requirements for the roofing system.

COMMON ISSUES IN LOW-SLOPE ROOFING AND HOW TO MITIGATE THEM

Challenges are faced by low-slope roofing systems, such as moisture intrusion and air leakage, affecting occupant health, safety, and energy efficiency.

In the early 2000s, due to the demand to reduce energy consumption, the urban heat island effect, and deaths occurring from the increased indoor temperatures, the cool or white roof membranes having a high albedo were implemented in many jurisdictions. The white roofing reflects the light of the sun during the day, thus reducing the heat gain of the roof. In the New York White Roof Project, it was calculated to save building owners 10% to 30% on their electric bills.[7] The color change did reduce heat gain.

A roof experiences the heat of the sun during the day and night-sky radiant cooling at night. Cool roof requirements, or high-albedo roofing, lowered the solar gain during the day, which reduced inward drying. This can be a problem, especially if air-transported moisture condenses on the interior side of the roof membrane during night-sky cooling

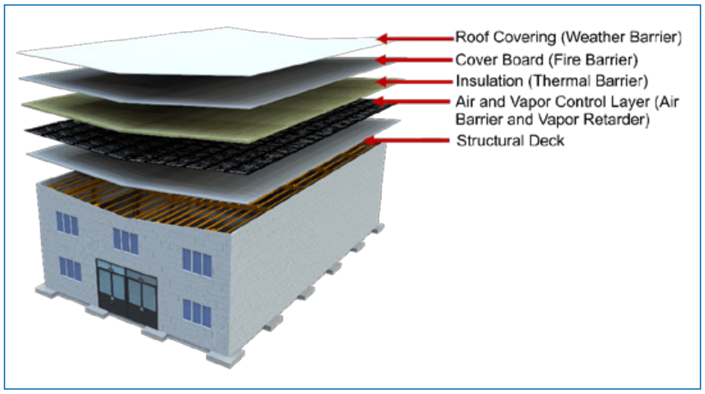

FIGURE 6. Overview of a low-slope roofing system.

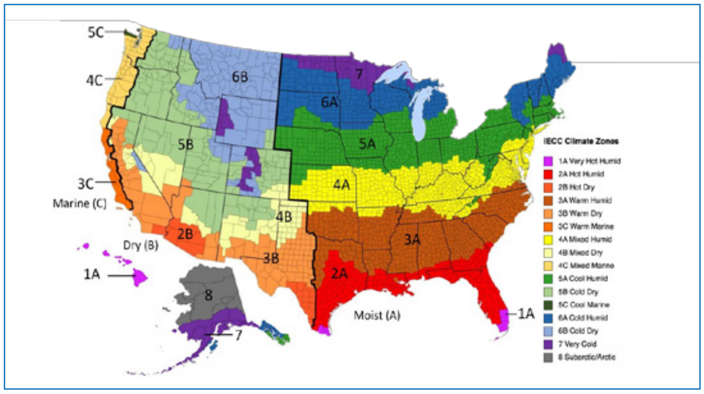

FIGURE 7. IECC climate zone map.

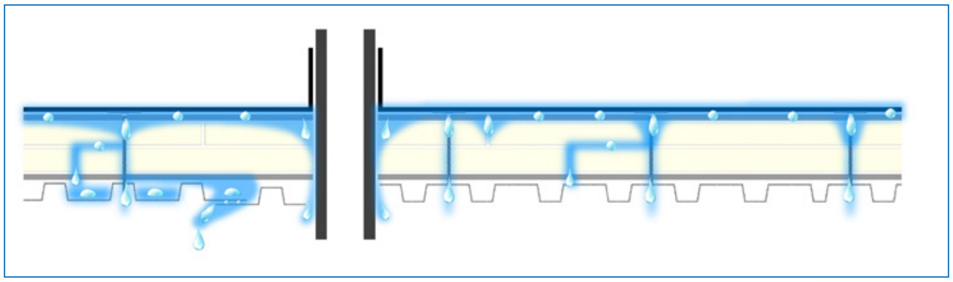

FIGURE 8. Condensation of moisture within the roof system due to air-transported moisture.

FIGURE 9. Image showing the damage caused by condensation build up on the wood deck. *Image from Phil Dregger, vice president at Salas O'Brien Company.*

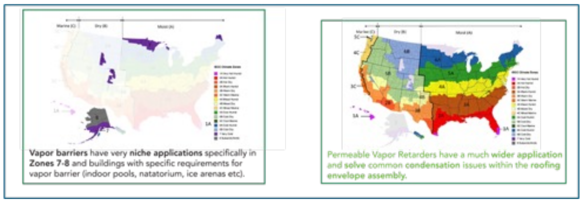

FIGURE 10. The climate map and climate zones where a vapor retarder may be needed.

(**Fig. 8** and **9**). The installation of an air barrier can control the source of the moisture, which is predominantly air transported. By incorporating a vapor-permeable air barrier, inward vapor-diffusive drying can relieve the potential accumulation of moisture within the roof system. Vapor permeance allows any moisture accumulation within the roof system to dry inward into the drier interior environment.

"Moisture trapped in or behind the cladding can be transported into the enclosure by solar-driven diffusion, especially in air-conditioned buildings. Rather than control vapor diffusion, a 6-mil (0.15 mm) vapor retarder close to the interior may, in many instances, exacerbate wetting and greatly retard drying."[8]

Vapor diffusion and vapor control are complicated. As noted in this paper, air-transported moisture issues are typically more common than vapor-transported moisture issues. In a colder climate, the cool winter weather vapor drive is outward; however, during the warmer summers, it is typically inward. Careful evaluations of the length of the cold winters and warm summers need to be considered. Since the low-slope roof membrane is both a water and vapor barrier, summer inward vapor drive is controlled. Considerations for the interior vapor retarder need to be determined. The climate zone and interior conditions can help determine the vapor permeance requirements. Typically, climate zones that experience long, cold winters require an interior vapor restriction to prevent outward vapor drive and the potential condensation within the roof system it may provide (**Fig. 10**).

The International Residential Code (IRC) and IBC requires a vapor retarder on the interior side of frame walls. This is typically referred to as the warm side of the insulation and does not address the complexities of the system. The low-slope roof membrane is a Class I vapor retarder preventing vapor drive. This provides inward vapor restriction or control during warm, humid weather but traps outward vapor drive in cold weather or during night-sky cooling. Should a Class I vapor retarder be used in the interior of the roof system in climate zones where winters are short or relatively warm, it would block any advantage of inward vapor-diffusive drying. Any moisture that enters the roof system would become trapped by the vapor-restrictive roof membrane and the interior vapor retarder. The specific classification of the vapor retarder and its inclusion and placement in the roof assembly are left to the designer.

"It is clear that any wet material (which will have an RH [relative humidity] of 95% to 100%) that is heated by the sun will generate large inward vapour drives."[9]

Using hygrothermal modeling such as the WUFI program, as a design review can eliminate some of the guesswork, though careful input is required. If done correctly, hydrothermal modeling can provide details for the potential of moisture buildup within the components of roof assembly. This analysis can guide a designer as to appropriate thermal and vapor restriction based on interior and exterior environments.[10]

Another crude method to consider is that of the National Roofing Contractors Association (NRCA) and Cold Regions Research and Engineering Laboratory (CRREL) recommendation. When the outside average January temperature is below 40°F (4°C) and the expected interior winter relative humidity is 45% or greater, an interior vapor retarder should be installed. Wayne Tobiasson's paper titled "Vapor Retarders for Membrane Roofing Systems" describes how this recommendation came about, but it also emphasized that airtightness that can accompany the vapor retarder application was more important than its vapor restriction.[11]

CASE STUDIES AND PRACTICAL APPLICATIONS

In this section, real-world case studies are examined, showcasing projects that successfully implemented modern air barriers and permeable vapor retarders in low-slope roofing. The case studies illustrate performance improvements and lessons learned, providing practical examples of how these technologies have been applied to enhance building performance.

The low-slope roof of the Tampa airport terminal building of over 120,000 ft^2 (1115 m^2) was failing, in need of replacement. The failing roof membrane and damaged roofing materials were removed. Immediately a self-adhered permeable roof underlayment was placed over the existing materials. The self-adhered underlayment was vapor permeable and dark in color, allowing the underlying roofing materials to dry. In addition, the permeable roof underlayment was also an air barrier, adding air tightness to the roof assembly. Once the existing materials were dry, additional insulation was placed over the vapor-permeable underlayment, additional insulation and the final roof membrane were installed.

The application of a watertight, vapor-permeable air barrier protected the exposed roof from water ingress, allowing the building to remain open. Some roofing material was left in place, minimizing waste removal and reducing labor costs. As an air barrier, it reduced energy consumption due to convective heat transfer and reduced air-transported moisture into the roof system, thus increasing the life of the roof and decreasing the cost of this investment. The vapor permeance allowed inward drying of moisture accumulation should it enter into the roof's system.

A garden roof of a condo complex was failing, causing water ingress into the units below. The roof system consisted of a vegetative green roof on a PVC roof membrane, 0.25 in. (6.35 mm) cover board, polyisocyanurate insulation, two layers of plywood, and 4 in. (10.16 cm) of spray foam insulation. To prevent a complete roof removal requiring occupant displacement, the overburdened roofing, membrane, and insulation down to the two layers of plywood roof deck were removed. A watertight, vapor-permeable air barrier membrane was placed on the plywood deck. The membrane was left exposed to allow drying of the underlying materials. Moisture content was measured until moisture content achieved safe levels around 40 days.

The watertight, vapor-permeable air barrier protected the exposed plywood deck from water ingress and allowed the deck to dry. This allowed the occupants to remain in their condo units, reducing revenue loss for the property owners. The addition of a permeable air barrier stopped convective heat transfer into the roofing system reducing energy consumption. Stopping air movement into the roofing system, controlled air-transported moisture, increasing the life of the roof and decreasing the cost of this investment.

A food processing requires strict food safety requirements and needed additional space. A fully adhered vapor permeable air barrier was installed directly over the cured concrete deck. This prevented additional moisture from reaching the concrete and internal space. The vapor permeable air barrier allowed construction of the roof system while the interior was being constructed. As a membrane the air barrier was easily incorporated into the wall assemblies air barrier system completing the continuity requirements for air tightness.

The vapor permeable air barrier provided surface protection and safeguard for the building against moisture intrusion. As a vapor permeable air barrier, it enables the roof system to effectively manage moisture. This prevents accumulation while allowing for moisture balance, thereby supporting the roof system's ability to adapt to varying environmental conditions, ensuring stability and extending the system's longevity.

CONCLUSION

The role of low-slope roofing in building performance is far more complex than merely offering protection from the elements. Effective moisture management, particularly the use of air barriers and vapor retarders, is essential to optimize a building's energy efficiency, durability, and overall health. Air barriers are crucial in preventing the ingress of air-transported moisture from infiltrating into roof assemblies, while vapor control becomes essential when vapor pressures are driven significantly outward of the conditioned space. A watertight, vapor-permeable air barrier offers substantial benefits by protecting the roof from water ingress, ensuring the building remains operational, and reducing waste and labor costs by preserving some of the existing roofing materials. This solution also provides energy savings by limiting convective heat transfer and mitigating air-transported moisture, thus extending the roof's lifespan. Moreover, the vapor permeance allows inward drying of any moisture accumulation, reinforcing the long-term durability of the roof system and enhancing the overall value of the investment.

By understanding when and where to apply these control layers, designers, contractors, and building owners can make informed decisions that lead to cost-effective, long-lasting roof systems. As building technologies and environmental challenges increase, the importance of air- and vapor-control layers continues to grow, ensuring that roofs meet the demands of modern architecture while contributing to a building's peak performance for years to come.

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