Design of effective building-envelope systems hinges on strategies to harness air, moisture movement

Devising a better barrier

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Moisture management, control of air flow, and energy efficiency represent three significant facets of a successful building-envelope design, and are closely connected in a cause-and-effect relationship—without effective management of moisture and air flow, energy efficiency will prove highly elusive.

Moisture movement into structures can take many forms. Large droplets of moisture from rain, sleet, or snow typically enter a building through weaknesses in fenestration seals or the exterior cladding. Once moisture enters a space and is trapped by the exterior material of the building, damage can occur. The wall is designed to limit the amount of moisture that enters a building this way.

Smaller amounts of moisture can also be carried in the air in the form of vapor, and can migrate through exterior cladding and interior building materials through vapor diffusion. When air pressure is added to the equation, the amount of moisture carried through the building envelope increases dramatically, as do the problems associated with moisture infiltration and exfiltration. Air movement into and out of a building is also one of the leading causes of energy loss in the building. Air barriers were developed to help combat these problems.

Water vapor can enter a building both above and below the building grade through diffusion. If no vapor barrier is present or if it is damaged or not installed properly, water can still penetrate. Below grade, groundwater can cause damage to the foundation materials if the foundation cracks. The best solution to this potential problem is to use a waterproofing product at the foundation level.

Vapor barriers, or vapor retarders, can also work effectively below grade to help reduce the migration of moisture through vapor diffusion or capillary action; however, they function less effectively on their own above grade when the dynamic forces of air movement are added to the equation.

Different types of moisture require different protection strategies. Some, like liquid water in the form of droplets, are easier to repel than airborne water vapor. This will be explained when we compare the amount of moisture carried above grade by vapor diffusion vs. the amount of moisture carried by air-pressure differential and the moisture present in that air.

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Air leakage and the associated infiltration and exfiltration of moisture are primary causes of many building-envelope issues, and can result in serious problems. For instance, corrosion of brick ties can lead to catastrophic wall failures; entire brick facades have fallen due to corroded ties. Excess moisture can lead to mold growth, which will lead to poor indoor air quality.

Air leakage is a primary contributor to increased loads on mechanical systems, leading to increased energy costs. If cold air can get in or out, HVAC systems are forced to work harder to maintain the interior atmosphere, contributing to increased energy consumption and operating costs.

Figure 1 provides an overview of the components that make up a good wall design. Structural elements constitute what holds the building up—blocks, concrete, wood, steel studs, etc. The façade is what protects the inside from the outside—the first line of defense in the form of brick, architectural block, siding, stucco, etc. Next are the components that make up the building-enclosure system: the heat barrier (insulation), moisture barrier, vapor barrier, and air barrier. The last three may take on the form of multiple products, or they may be combined in one element; that depends on the design of the product used.

Figure 2 provides a glance at the building enclosure system, composed of the heat barrier, moisture barrier/drainage plane, and vapor barrier/retarder.

The moisture barrier/drainage plane prevents potential liquid moisture intrusion into and through the building-enclosure system; the vapor barrier/retarder limits wetting potential due to vapor diffusion into and through the building enclosure system; and the heat barrier, or insulation, resists thermal transfer through the building enclosure system. These strategies and materials have been utilized for years and their impact on the building enclosure are well documented and understood. An effective above-grade building-enclosure system will also include an air-barrier system and a moisture-barrier system. It may also require a vapor barrier.

Inattention to the building envelope can result in damage to other components of the building. As a result, air and vapor barriers have played a major role in construction in recent decades.

The above-grade building-enclosure system

A good design that includes an air barrier, moisture barrier, and potentially a vapor barrier will function more effectively than a wall without these technologies. Effective wall assemblies exhibit the ability to store moisture, and possess a greater drying potential than wetting potential. The placement of these items in the wall assembly are critical, since a "good" wall must be able to dry. We will never prevent all moisture from entering a wall assembly. But as long as the wall has a greater drying potential then wetting potential we have an effective wall from a moisture standpoint. In simple terms, if a building component gets wet, it must be able to dry.

Two types of moisture movement occur above grade: movement by vapor diffusion and movement by air-pressure differential. We will discuss these sepa-

Facing page, above, and right: Proper application of air and vapor barriers is critical to the success of the building-envelope system. Barrier types include self-adhering (peel-and-stick) membranes and liquid-applied membranes based on rubberized asphalt emulsions and acrylic resins. The manufacturer should be consulted for any special installation recommendations.
Photos courtesy of W.R. Meadows Inc.

Wall Design – Components

- Structural
- Façade
- Heat Barrier
- Moisture Barrier/Drainage Plane
- Vapor Barrier/Retarder
- Air Barrier

Building Enclosure System

Fig. 1

Building Enclosure System

Heat Barrier
–Resists thermal transfer through the building enclosure system
Moisture Barrier/Drainage Plane
–Addresses wetting potential due to liquid moisture intrusion into and through the building enclosure system.
Vapor Barrier/Retarder
–Addresses wetting potential due to vapor diffusion into and through the building enclosure system.

Fig. 2

rately, and the effects they exert on a structure.

Moisture movement above grade

As early as the 1950s it was becoming clear that air leakage was instrumental and common in the majority of building-envelope problems and failures. Air leakage played a part in rain penetration, condensation problems, excess heat loss, drafts, etc. Air leakage dramatically affected the energy efficiency of the building, and the damaging effects of air leakage on a structure were beginning to be understood. Not only did air leakage affect the moisture in a wall assembly, it dramatically affected the energy efficiency of the building. This was the start of our understanding of the total building envelope.

Think of the building envelope as a beach ball. If the ball has a small hole, or is not made of a strong material, it will be punctured and begin to leak. The same goes for the building envelope. If it is not airtight, continuous, durable, and structurally sound, the building will leak air and moisture.

Air flow into and out of buildings is a cumulative result of many different pressures, including wind, fan, and stack pressures (Figure 3).

Wind pressure is the force of the outside air "blowing" into the building. Fan pressure is the mechanical pressurization of the building, typically creating an area of high pressure within the structure as compared to the exterior environment. Stack pressure is created when air in the building is heated. During the heating season, this heated air will rise, creating higher pressure at the top of the structure. This effect is greatest in cooler climates.

Wind pressure is the pressure or force of air entering and leaving a building. For example, if it's summer, warm air is entering the building and cold air is leaving the building. Warm air is being forced in through weak spots in the envelope or through fenestrations, and cool air is being "sucked" out through the areas of the building where a suction force has been created.

Fan pressure is the amount of pressure or force that internal air flow exerts on the building or its interior circulation. Stack pressure is created when the air in a building is heated; as the air warms it tends to rise, resulting in an area of higher pressure at the top of the structure. The stack effect is most prevalent in cooler climates. This area of high pressure will try to migrate to an area of lower pressure outside the building, taking warm, moist air with it.

Wind, stack, and fan pressures are

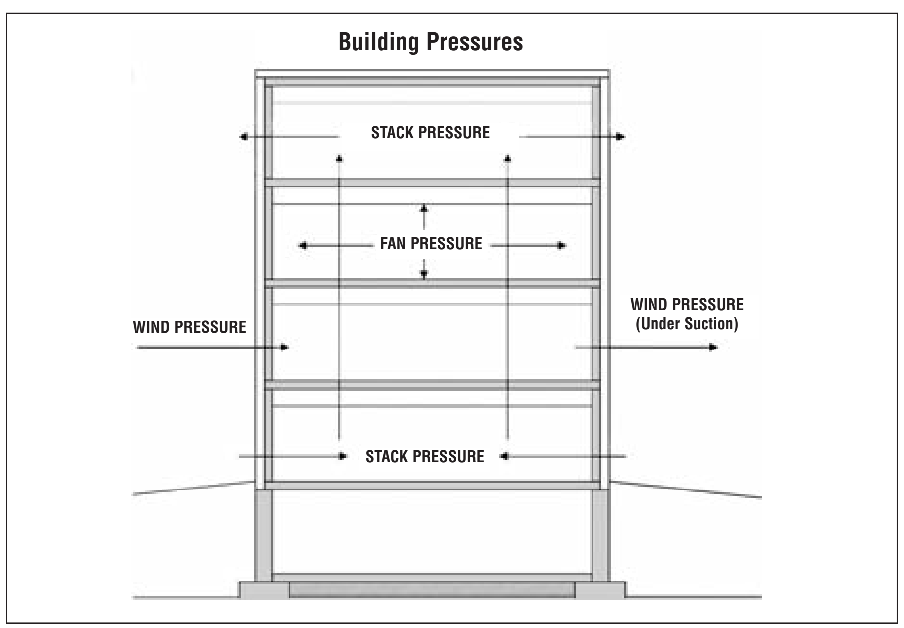

Fig. 3

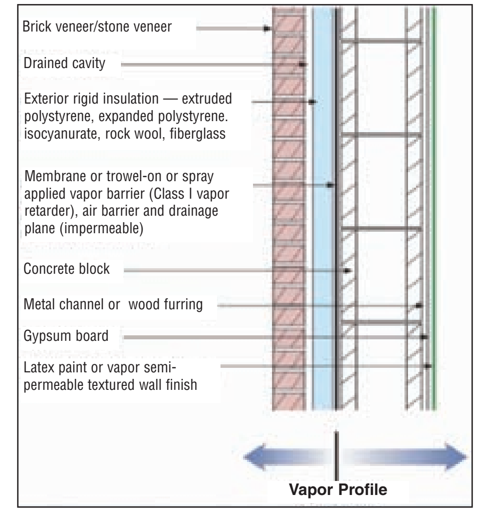

Fig. 4: Air and vapor barriers can also act as a drainage plane should moisture penetrate the envelope. The barrier prevents further penetration of moisture to the interior wall system and drains the moisture from the wall cavity. In essence, it guides the moisture away from the interior wall cavity to the exterior. Diagram courtesy of: Buildingscience.com

examples of the forces that act on a building. The air barrier has to be designed to deal with these forces.

Vapor movement and terminology

Water-vapor diffusion is caused by a vapor-pressure differential between different environments. The greater the vapor-pressure differential between environments, the greater the amount of vapor diffusion. Vapor diffusion is the process by which vapor seeks to equalize its content between different environments (The Ideal Gas Law). When an imbalance of vapor exists between two environments, the environment with the higher concentration of the vapor will diffuse into the area with lower concentration of the vapor. The driving force (or "potential") for this occurrence is vapor pressure.

The dew point

Many contemporary building-envelope designs continue to be based on a dew-point calculation. While dew point is critical to a good design, it does not take into account the other issues affecting the building, such as air movement and precipitation. The dew point is the temperature at which air that contains a certain amount of vapor can no longer hold that vapor and must exhaust itself of excess vapor by depositing it on adjacent surfaces in the form of condensation.

While condensation on a glass or bottle may cause the surface on which it sits to get wet, that is a minor inconvenience. We want to control where this happens in a wall. Moisture in the wrong place, on the other hand, presents a major a problem. A vapor retarder and heat barrier have a great impact on where the dew point forms.

Today we have more sophisticated tools available that go beyond what a simple dew point calculation can provide. A commonly used building envelope tool is called WUFI and is available on the internet.

Air and vapor barriers can also act as a drainage plane should moisture penetrate the envelope. The barrier prevents further penetration of moisture to the interior wall system and drains the moisture from the wall cavity. In essence, it guides the moisture away from the interior wall cavity to the exterior.

The specification of an air-barrier system can help address building-enclosure system problems and reduce energy consumption for heating and cooling. This in turn leads to an overall reduction in operating costs and decreased dependency on fossil fuels used to create the power to run the building. A decrease in fossil-fuel consumption means that fewer harmful gas emissions will occur during operation, and lower gas emissions can help mitigate the greenhouse effect. And yes, the indoor air quality is improved.

The U.S. Department of Energy has determined that up to 40% of a building's energy consumption for heating and/or cooling the building is due to air leakage. Thus, the DOE has instituted a program of goals to reduce building energy consumption by 25% by the year 2010 and 50% by the year 2020.

Vapor barriers and air barriers

Vapor barriers or vapor retarders are materials used in building enclosure systems to retard the diffusion of moisture in its vapor form into and through the building-enclosure system. They prevent diffusion in relatively small amounts above grade and in larger amounts below grade, and do so independently of air pressure. Thus, these barriers minimize or prevent conditions that create dew points within the building enclosure system, helping to maintain a constant interior atmosphere.

Air barriers, on the other hand, block the movement of air under pressure. Air drastically increases the amount of moisture that is able to penetrate the vapor barrier, which is why the use of an air barrier is also important. Air movement accounts for upwards of 70-90% of the moisture moving through the building envelope; moisture movement by vapor diffusion accounts for only 10-30%

An air barrier is a system of components within the building envelope designed, installed, and integrated so that together, the system can prevent the uncontrolled flow of air into and out of the building.

Air barriers and air/vapor barriers (vapor-impermeable air barriers) control the movement of moisture by forced air and by vapor diffusion through the building envelope. They also control movement of moisture from precipitation. A combined air/vapor barrier performs the duties of three separate products in one: air barrier, vapor barrier, and moisture barrier/drainage plane.

Air/vapor barriers will work in most buildings. They work in all climate regions, in buildings with high interior moisture loads, and in humidified and dehumidified buildings. Proper placement of the heat barrier is critical when using an air/vapor barrier. Vapor-permeable air barriers, on the other hand, are designed to allow moisture to diffuse through the wall, and function as an air barrier and as a moisture barrier/drainage plane. They are only recommended for use in specific climates and in specific wall systems.

This photo shows an example of moisture leakage through a wall. The moisture picks up the salts from internal wall materials as it is moves from inside the building to the outside. When the sun comes out, the salt solution dries, leaving a salt deposit, called efflorescence, on the surface. Efflorescence is a possible sign of a building-envelope problem.

Here is another, perhaps more extreme example of moisture leakage. Enough moisture has leaked to form icicles on the exterior of the building.

Vapor-permeable air barriers work well in climates that are mild or dry for a majority of the year. Certain parts of the southwestern U.S. are a good example of a dry climate where a vapor-permeable air barrier could be used. The climates of the Midwest or other colder regions may not be conducive to the use of vapor-permeable barriers; however, this depends on the wall design, placement of the heat barrier, and whether a separate vapor barrier is used.

Designing effective air-barrier systems

Factors that determine the effectiveness of an air-barrier system are design, materials, workmanship (installation), and quality assurance (warranty). Without good workmanship, design and materials are irrelevant because even the most effective material could be installed improperly and be rendered ineffective. Job-site inspection and quality assurance are important.

In the design stage, it must be determined if the structure requires a vapor barrier as well as an air barrier. If the design includes a vapor barrier, it is important to take into account insulation, foil back, or interior finishes such as non-permeable vinyl wall paper. If a combination air and vapor barrier is used, care must be taken to ensure the interior finish doesn't create a double vapor barrier that can trap moisture in the wall assembly.

Different wall-assembly systems will work in different areas of the country, and some will work everywhere. These areas are categorized into hydro-thermal regions that are defined by the ratio of heating and cooling days, as well as average rainfall totals. Humid, high-moisture environments along coastlines will likely dictate the need for additional moisture-preventing technology than cooler and dryer, inland climate regions.

Selecting the air barrier

When considering whether the air/vapor barrier or vapor-permeable air barrier is right for the given project, the following key factors should be weighed.

- What is the intended and potential use of the building and in what climate zone is the building located?
- What type of indoor conditions will be required and where will the air barrier have to be located to achieve the desired conditions?
- What type of construction will be specified and what type of building enclosure system will be employed?

When determining where the air/vapor barrier will be installed, the first consideration is the location of the heat barrier (insulation) relative to the air and vapor barrier.

The building profile shown in Figure 5 portrays how exterior walls were built 30 years ago. The rigid insulation and dampproofing provide a decent moisture barrier. The CMU has a high moisture storage capacity, allowing it to encourage migration of vapor away from the interior. The problem, however, is that the wall wasn't designed to incorporate an effective air barrier. CMU is a porous substrate that allows flow of air. Still, we were almost there!

Today we can take that design, add a true air barrier combined with a vapor barrier and moisture barrier, and we have the perfect wall (Figure 6). The only drawback may be that this wall comes at a cost, perhaps too high a cost for some types of construction. Still, it remains the best wall you can build.

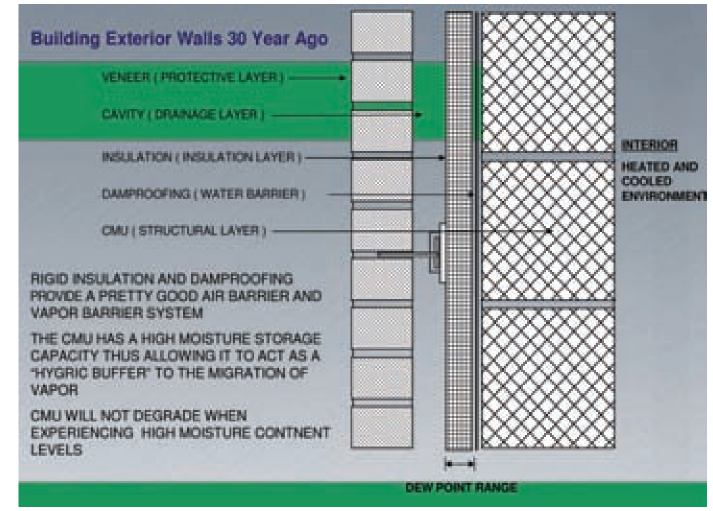

Fig.5

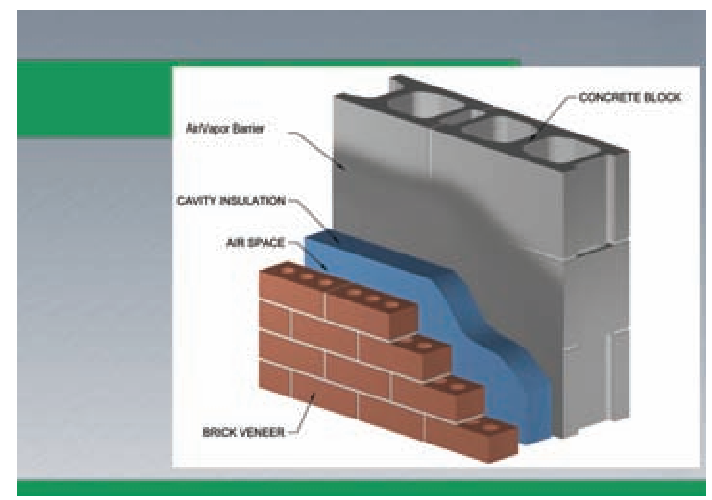

Fig.6

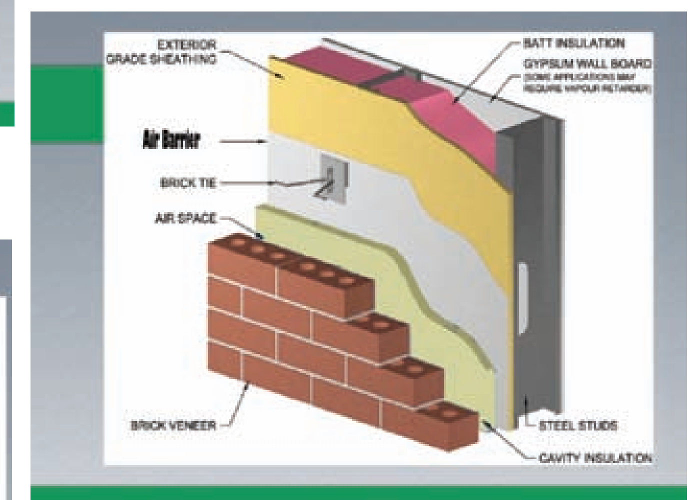

Fig.7

Now let's look at vapor-permeable air barriers. These membranes are effective air barriers and moisture barriers, while the high vapor permeance allows vapor to pass through.

Figure 7 depicts a typical example of a wall incorporating a vapor-permeable air barrier. Note that if insulation is used in between the steel studs, a secondary layer should be placed in the cavity on top of the air barrier to stop the thermal transfer across the steel stud and help maintain the system R value. The choice of the insulation in the cavity is critical as in this case it must be permeable. In some states a separate vapor retarder on the interior may be required by code.

Effective air-barrier system materials should be capable of withstanding positive and negative wind loads, fan and stack pressures. They should be durable and maintainable. They should be installed in a continuous manner, so that all joints, laps and seams are tight. They should be able to be used with different substrates, and should be able to adjust to the expansion and contraction values of compatible substrates. Perhaps most importantly, they should have an air leakage rating not exceeding 0.004 cmf/sf under a pressure differential of 75pa.

Types of air and vapor barriers

Elastomeric bitumens and synthetic rubber-based mastic barriers were among the first materials used after air and air/vapor barriers became a commonplace building feature. This type of material is rarely used today due to the high labor cost for installation.

In some climates, torch-applied roof membranes were adapted to create an air/vapor barrier. These systems are very difficult to install correctly; when installed incorrectly, adhesion can be a problem. The loads on the structure from wind can cause premature envelope failure. These membranes are also dangerous for the worker, and can present a hazard for the structure as an open flame is used in application. This type of membrane is seldom used today.

Spray-in-place urethane foam can act as an air barrier. A separate moisture barrier, flexible in nature, should be applied first to the substrate.

Self-adhering (peel-and-stick) membranes are based on SBS-modified asphalt laminated to high-density cross-laminated polyethylene. A key benefit of this type of material is controlled thickness, but detailing at all the ties presents an issue. In addition, it is important to note that not all peel-and-stick products are equivalent in terms of performance. In addition, the adhesives often are subject to specific installation temperature ranges and other weather-related considerations, and if these are disregarded the application may fail. It is important to consult the manufacturer for specific installation recommendations.

Liquid-applied air/vapor barrier membranes currently experiencing widespread use include rubberized asphalt emulsions and other waterborne formulas based on acrylic resins. The waterborne asphalt emulsion products offer the advantages of relatively modest applied cost, seamlessness of the membrane, and the safety, convenience, and environmental benefits of waterborne chemistry. If early rainfall resistance is important, single-component rubberized asphalt membranes provide superior performance in comparison to other formulations.

Proper application of the air/vapor barrier is paramount to the success of the building-envelope system. The manufacturer should be consulted for any special installation recommendations to ensure that the product specified and the building to which it is applied will perform to their maximum potentials.

Application guidelines

If a sheet membrane is applied to a block wall, the excess mortar is removed, the surface is allowed to dry for priming and application of primer, the sheet membrane is applied, and the mortar ties are detailed. If a rubberized asphalt emulsion is used, the mortar droppings are removed, but drying of the wall is not needed.

The process is simpler with liquid air/vapor barrier applications. Priming is not required; nor is drying of a surface that has become wet, depending on the product formulation. The excess mortar is removed, followed by application of the liquid-applied membrane and detailing of ties. With the application of a liquid membrane, field testing to assure the specified membrane thickness has been achieved is conducted with a wet film gauge.

With liquid membranes, peel and stick materials are still required for transitions, flashing, and detailing of large cracks or voids.

Liquid-membrane technologies are based on different formulas, and vary in their performance characteristics. If the masonry anchors are installed after the air barrier, a barrier material that self seals may be preferable. Rubberized asphalt will typically self seal, as will some acrylics, depending on the manufacturer.

Care should be exercised where corrosive accelerators are involved. Here, a recommendation would be to use fast-drying formulas that don't require the use of calcium chloride (salt) to set.

The Air Barrier Association of America provides details, education, and quality-assurance reference materials on air-barrier specification and application on the website located at www.airbarrrier.org.

It is recommended that specifications include a requirement for an ABAA-licensed contractor, certified applicator, or registered ABAA installer.

The payoff

Proper moisture management and effective sealing of a building can prove to be one of the most effective ways to prolong building life, improve indoor air quality, and dramatically increase the energy efficiency of a structure. When designed and installed correctly, these measures deliver a swift payback to the owner. In addition, many states and other jurisdictions are adopting building codes that address the problems associated with air movement and moisture infiltration.

When selecting, designing, and installing air- and vapor-barrier systems, it is important to choose the best product that meets the needs of the project, the budget, and the anticipated design lifetime. Installations should be executed and inspected by licensed contractors and consultants. Information on licensed contractors can be found on the Air Barrier Association of America website, located at www.airbarrier.org.

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