Technical Features − Water Resistance
What You Ought To Know About Air Barriers And Vapor Retarders

By Paul H. Shipp, PhD, P. E., Construction Technology Laboratory, USG Research Center, USG Corporation, and Maurice J. Marchello, Architectural Construction Systems Department, United States Gypsum Company

(Editor’s Note: This article originally appeared in the 1989, Issue 1 of Form Function. Some pictures, graphics or charts may not appear in this version. To receive a printed copy of this article, or information about the products mentioned in it, contact: Editor, FORM FUNCTION, 125 South Franklin Street, Chicago, IL 60606−4678.)

Air barriers and vapor retarders are critical elements in controlling air leakage and condensation in the exterior envelopes of most modern, energy−efficient buildings. Their specification remains a matter of debate and uncertainty, however, while moisture continues to adversely affect durability, esthetics, energy efficiency and comfort in many buildings.

Problems with air barrier and vapor retarder systems are often attributed to field conditions, such as the materials used, methods of construction and quality of workmanship. But, while these are important, the evidence suggests that many problems originate earlier in the building process, during the design and specification phases.

One reason for problems is the confusion that is common regarding the function of air barriers versus vapor retarders and the unique performance constraints imposed upon each. A single barrier is often used to serve both functions. While this can be appropriate in certain applications, if the materials and conditions of use are not considered for each application, the entire design can be rendered ineffective or even damaging. A clear understanding of these differences is essential to the successful design and construction of air leakage and condensation control measures.

Control Of Airborne Moisture
Air barriers and vapor retarders control the entry of airborne moisture into walls and ceilings. The two moisture transport mechanisms that play a major role in this are diffusion and air leakage, or convection.

Air consists of a mixture of gases, one of which is water vapor. Each gas exerts a pressure proportional to its concentration in the mixture. Accordingly, the water vapor pressure represents the moisture's contribution to the total air pressure. In general, vapor pressure increases with increasing moisture content in the air.

Diffusion is the process by which water vapor migrates through a material due to a difference in vapor pressure (see Fig. 1a in original article). If the air inside a building has a different moisture content than that outside, the corresponding difference in vapor pressures will cause moisture to diffuse through the building envelope from the region of high moisture content towards the region of lower moisture content. The rate at which moisture migrates depends upon the magnitude of the vapor pressure difference and the resistance of the materials to water vapor diffusion.

For any given temperature, there is a maximum amount of moisture that air can hold. This level, known as the "saturation moisture content" (or 100% relative humidity), will decrease as the temperature drops. As a result, the air on the cold side of a wall or ceiling assembly usually has a lower moisture content than the air on the warm side. The resulting difference in vapor pressure generally drives moisture from the warm side of the wall or ceiling to the cold side.

When warm, moist air is cooled to its saturation temperature, or dew point, it has a reduced capacity to hold moisture. If cooling continues below the dew point, the air must release moisture by condensation in order to maintain the proper saturation level. Evidence of this process is frequently seen in the formation of fog, or water droplets on a cool surface. The functional relationship between vapor pressure, saturation moisture content (or relative humidity) and air temperature is presented in a graphic format by a psychrometric chart (ASHRAE Handbook−−1985 Fundamentals, American Society of Heating, Refrigerating and Air−Conditioning Engineers, Atlanta, GA, 1985.) See Fig. 2. (See original article)

Use Of A Vapor Retarder In Walls

Diffusion takes place when there is a difference between the water vapor pressure of the outdoor air and the building interior (Fig. 1a). Occupancy and comfort requirements make it undesirable to try to control diffusion by adjusting indoor temperature or humidity conditions. Therefore, the designer's only option for limiting and controlling moisture diffusion is to increase the building envelope's resistance to water vapor diffusion by use of a vapor retarder. Placement of the vapor retarder, however, is strongly influenced by climate and wall thermal resistance.

Fig. 3 (See original article) illustrates the construction and insulation values of a typical wall for residential and low−rise commercial construction throughout the U.S. It consists of a 4−in. face−brick veneer separated from the framed elements by an air space. Asphalt−impregnated gypsum sheathing is attached to the exterior of the framing with R−11 mineral−fiber insulation in the stud cavities and gypsum panels on the interior side.

An assessment of the moisture performance of a wall must first consider the thermal resistance (R values) of the wall elements to determine the temperature distribution within the wall. The saturation pressures for the temperatures in the wall can then be compared with the vapor pressure distribution calculated from the vapor permeance of the wall elements. The potential for diffusion to cause a condensation problem in the wall can then be determined. The calculation procedures used for these estimates are described in detail in the ASHRAE Handbook previously noted.

Consider the cold climate performance of a wall with the outside air at 24° F. and the inside air maintained at 70° F. and 50% Relative Humidity (typical January conditions for Chicago).

Using the thermal resistance values listed in Fig. 3, an illustration can be created to show the interior wall temperatures determined for these conditions (Fig. 4)(See original article). From a psychrometric chart (Fig. 2), the dew point for the interior space is determined to be 51° F. Since the moisture content is higher in the air inside the building, the vapor drive is from the inside out through the wall. And since the surface temperature of the exterior sheathing is well below the interior dew point temperature, it can be anticipated that the wall will experience condensation at the point in the wall where the temperature drops below 51° F. (if no interior vapor retarder is provided to reduce the rate of vapor flow).

This example confirms the conventional wisdom of placing the vapor retarder on the "warm in winter" side of the wall. But confusion arises when one considers a wall located in a warm, humid climate. As shown in Fig. 5 (See original article), humid climates in the U. S. follow the coastal belt of the Gulf of Mexico, south Atlantic coastal areas and Hawaiian Islands.

For an average June day in this region, consider our brick veneer wall with outdoor conditions of 86° F and 90% Relative Humidity (R.H.) while the building is air conditioned to 70° F and 50% R.H. The resulting temperature profile is shown in Fig. 6 (See original article). The vapor pressure drive is now from the outside towards the inside of the building. With an outside dew point of 83° F, it can be anticipated that moisture will condense on the back side of the interior gypsum panel where the temperature is 71° F, well below the outdoor dew point.

In this case, if the vapor flow is sufficient to indicate the potential for moisture problems, a vapor retarder should be located on the exterior side of the insulation using either a separate vapor retarder or a sheathing product that incorporates a retarder. This case points out the need for caution when using heavy vinyl wall covering or foil−backed gypsum panels on interior surfaces in humid climates, as these low−permeability facings (see Table 1) can cause moisture to condense and collect on the stud side of the panels.

Resulting problems can include staining at the base of the wall, mold and mildew growth and blistering of wall coverings. If a vinyl covering is essential, one might consider furring the interior surface from the exterior wall and venting the air space created.

The requirement and location for a vapor retarder should be determined by a qualified engineer. For instance, there is a fringe area depicted in Fig. 5 where neither winter nor summer conditions dictate the need for a vapor retarder. In that instance a vapor retarder may not be required at all, since the wall could be allowed to breathe without concern for condensation.

Use Of An Air Barrier In Walls

The second mechanism by which water vapor can be transported into a wall is by air leakage, or convection. This occurs when openings within the building envelope form a continuous path from the inside to the outside of the building and an air pressure difference acts upon it (Fig. 1b). Often these paths are quite circuitous and not obvious to casual inspection.

In the diffusion process, individual water vapor molecules pass through the building materials as sand passes through a sieve. By contrast, convection is a bulk transport mechanism in which the water vapor is swept along with the air mass. Air leakage through even a small opening can have a greater impact upon moisture condensation in the wall cavity than diffusion.

Quirouette determined that in one month as much as 31 lbs. of water could leak through an electrical outlet with a net opening area of 1 sq. in. and a pressure difference equivalent to a 9.3 mph wind. (Quirouette, R. L., "The Difference Between a Vapour Barrier and an Air Barrier," BPN 54, NRC Canada, 1985.) He estimated that over 233 times the amount of moisture would condense from air leakage than that passed by diffusion alone.

The two mechanisms occur simultaneously and operate independently of each other. The vapor retarder must provide a high resistance to vapor diffusion and must be located on the warm side of the condensing plane, but the air barrier is not constrained to do so. The air barrier's function is to stop outside air from entering or infiltrating the building through the wall and inside air from exfiltrating. To do this, the air barrier must seal the openings in the building envelope and be strong enough to withstand the physical buffeting of the air pressures acting on it.

A combination of three primary effects contribute to the total air pressure acting on an air barrier (Fig. 7) (See original article). The first is stack effect. Also known as the "chimney effect," this results from the thermal buoyancy of air due to changes in density with temperature. During winter, the warm air inside a building rises and exits near the top. This, in turn, draws in cooler air at the bottom of the building. This effect produces an outward pressure over the top half of the building and a suction force at the bottom. During summer, air conditioning causes the pressures and flow directions to be reversed.

The second driving mechanism is wind pressure. Airflow around and over a building creates a positive pressure on the windward side driving infiltration. Suction pressures cause exfiltration on the leeward side. The pressure differences vary rapidly with time due to turbulence and changes in wind direction. Since wind speeds increase with height, wind−driven pressure differences across the building envelope also increase with height.

The third source of air pressure differences comes from mechanical ventilation provided by fans. These produce pressure differences that are distributed rather uniformly over the envelope area. Being a sustained load, however, even small fan pressures can have a significant effect upon the air barrier by forcing some materials out at joints or to come apart at seams.

While the location of an air barrier relative to the condensing plane within the wall is not critical, it can be argued that placing it towards the conditioned space reduces stresses by insuring more constant temperatures. An intact and functioning air barrier prevents the vapor retarder from having to resist pressure loads. Since the pressure field around the building is constantly changing, the air barrier must be designed to withstand both positive and suction pressures at all points. Methods of attachment to the building require close scrutiny to insure that they are adequate for the job. Likewise, if a flexible material is used it must be properly supported on both sides. If the air barrier or its attachment system is unable to resist the peak air pressure loads, it will be damaged or displaced and thus rendered inoperable.

Common Problems And Good Design Practice

Many of the problems associated with water vapor condensation in building envelopes originate in the building design process. Recognition of the importance of both air tightness and vapor diffusion control and the different demands each function places on the control system is an essential element of successful design and implementation. The vapor retarder and the air barrier may or may not be the same material. If a single material is used to serve both functions, then it must be able to meet the requirements of both air tightness and vapor diffusion control. If different materials are used to provide separate air barrier and vapor retarder systems, then each need only satisfy the requirements of its particular function.

USG Corporation companies market many building products that function as air barriers and/or vapor retarders. These and related products are listed in Table 1 (reproduced below) with applicable performance data. Proper selection, detailing and installation are essential to achieve desired results. The following are tips on how to avoid common problems encountered in dealing with air barriers and/or vapor retarders.

Many regard a vapor retarder as a material with a resistance to diffusion of one perm or less of water vapor (see notes in Table 1). However, a specific building design may require much less than one perm (1.00). For instance, one accustomed to using foil−back products (usually 0.06 perms or less) should not switch to an alternate material without first verifying the perm rating.

Note that #15 felt, paper−backed metal lath and TYVEK Housewrap are air/water barriers, not vapor retarders. On the other hand, polyethylene film, four mils or heavier, is both an air barrier and vapor retarder. Thus its placement in the wall must coincide with the required location for vapor control.

Two vapor retarders on opposite sides of a single wall can trap water vapor between them and create moisture related problems in core materials. Consequently, SHEETROCK® Brand W/R Gypsum Panels may function as a base for ceramic tile and as such must not be installed over a vapor retarder. Doing so could trap moisture in the gypsum core since the tile membrane finish may act as a vapor retarder (if set in a mastic adhesive).

If vapor retarders are designed to be used on opposite sides of a single wall, vapor retarder materials should be selected to provide five times the vapor resistance on the "warm side" of the assembly as that on the "cold side." The popular use of rigid foam insulation on the cold exterior side of walls presents such a condition. For example, when 2−in. extruded polystyrene (about 0.6 perms vapor resistance) is used on the cold side of a wall, the warm side would require a vapor retarder of 0.12 perms or less. A foil−backed product of 0.06 perms properly installed on the warm side of the wall would be suitable. For a ceramic tile base, DUROCK Interior Cement Board would be the preferred choice assuming the tile finish is 0.12 perms or less.

A common error in buildings with suspended ceilings is to neglect treatment of drywall surfaces within the ceiling plenum on exterior walls. Since the plenum is not visible, care should be taken to make sure that this area is not overlooked. The drywall application and joint treatment should be carried all the way to the spandrel beam or floor structure above. Exterior ceilings and soffits are other areas that may be forgotten. Ceilings, soffits and cutouts for pipe, conduit, knee braces and vent penetrations should be carefully treated to avoid compromising the effectiveness of the vapor retarder and/or air barrier.

Penetrations in the exterior wall for windows, doors, outlets, HVAC and other fixtures or devices must be closed tight with sealant or tape. A good rule is to treat the exterior wall with the same detailing as that used for acoustical isolation (Fig. 8) (See original article).

Exterior walls that employ foil−faced THERMAFIBER Curtain Wall Insulation should also use foil tape to close joints, penetrations and damaged areas. If applied in a furred exterior wall without sheathing or backing, insulation must be adequately fixed to the framing so it won't be dislodged by air movement in the wall cavity. In this instance, do not rely on a friction fit.

THERMAFIBER Safing Insulation and SMOKE SEAL Compound not only provide a fire/smoke barrier at the floor intersection with curtain walls, but also reduce vertical movement of air due to the stack effect. Accordingly, mechanical attachment of insulation by impaling pins or clips is required.

Exterior walls of wood or steel−stud construction should be sheathed to protect the stud cavity. An overlayment of TYVEK Housewrap or #15 felt provides an effective air barrier. Particular attention should be given to provide a tight interface at windows and doors using appropriate sealant or tape and flashing details.

Control joints required for exterior finishes are by definition a location for planned movement of the surface. They should also be recognized as points of potential air and water infiltration. Accordingly, the control joint should be flashed and/or sealed to prevent infiltration.

When a polyethylene vapor retarder is used behind gypsum panel ceilings under cold conditions, ceiling insulation (batts, loose fill or blown in) should be installed at the same time or immediately after the vapor retarder and ceiling are installed. Also, the plenum or attic space should be properly vented. Failure to do the above can result in moisture condensation on the back side of the gypsum panels from the moisture load caused by the construction process, causing the drywall to sag.

Finally, while vapor retarder and air barrier details are often handled adequately over flat, visible surfaces, systems frequently will fail because proper consideration has not been given to maintaining the integrity and continuity of these systems at intersections and hidden penetrations. Details for floor/wall and roof/wall connections are the most difficult and important design challenges. Special attention and care should thus be given to intersections of assemblies and penetrations to insure their integrity of air tightness, vapor diffusion and thermal resistance.