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Air and Vapor Barriers for Southern Buildings

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Introduction

Investigations of building envelope problems have led many building science consultants, investigators and researchers to conclude that air leakage is the leading cause of moisture problems in exterior building envelopes. These problems include mold and mildew in exterior walls, excessive rain penetration into wall cavities, poor indoor temperature and humidity control, high air conditioning costs and compromised noise, fire and smoke control measures. In colder climates the problems of air leakage include icicles on exterior facades, spalling of masonry, premature corrosion of metal parts in exterior walls, high wood moisture contents and rot, excessive rain penetration and indoor temperature and humidity control problems.

Moisture in wall cavities is not only caused by air leakage and rain penetration. It is also caused by the diffusion of moisture through materials from exposure to high humidity conditions. In the late forties and early fifties, water vapor diffusion was considered the most significant source of moisture in insulated walls in northern climates. This article examines the need for different types of barriers in exterior walls and windows, specifically the need for air and vapor barriers for buildings in the southern United States. It provides guidance with respect to exterior wall air and vapor barrier design, the selection of air and vapor barrier materials, as well as the effects of building ventilation and building air pressure on wall cavity moisture balance.

Vapor Diffusion and Vapor Retarders

In the late 40's, it was discovered that moisture could accumulate in the cavities of insulated exterior walls. In 1947, Professor Rowley of the University of Minnesota determined that indoor humidity penetrated through the indoor finish of an exterior wall to condense on the backside of an exterior building paper, wood sheathing or wood siding. It was also determined that the indoor humidity could be prevented from entering the wall cavity by placing a moisture resistant material on the warm side (high vapor pressure side) of the exterior wall. This vapor resistant material was soon required in the construction of insulated exterior walls and eventually defined as the vapor barrier of the exterior wall.

Vapor Barrier Testing

The science and technology of vapor barriers evolved quickly. Further research eventually established that the property of interest in vapor barriers was vapor diffusion (the perm) and vapor diffusion resistance (the rep). Soon building design guidelines were established; a test method (ASTM E-96) was developed to identify and qualify vapor barrier materials and a building code regulation with respect to vapor barriers was adopted. In the ASTM E-96 test method, there is a wet cup (A) or dry cup (B) method which may be specified. Both test methods measure the weight of water vapor which passes through a given area of material over a specified interval of time. The result is usually expressed as water vapor transmission (WVT) in grains/h.ft2 and vapor permeance in perms, (grains/h.ft2.in-Hg). From the late fifties and early sixties, most buildings with insulated exterior walls were required to incorporate a vapor barrier.

The perm rating of a material is defined as the number of grains of water (7000 grains =1 lb) passing through a material under a given vapor pressure difference over a given area and for a specified interval of time. Specifically, a perm rating of 1 is defined as the passage of 1 grain of water vapor passing through 1 square foot of material under a vapor pressure difference of 1 inch of mercury (Hg) over a 1 hour interval. The vapor permeance of a material is defined as the time rate of water vapor transmission through a unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions. The vapor permeability of a material is defined as the time rate of water vapor transmission through a unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

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Water vapor transmission (WVT) is the steady water vapor flow in unit time through the unit area of a material, normal to parallel surfaces, under specific conditions of temperature and humidity at each surface.

Vapor Barrier Materials

A vapor barrier must include various properties but the most important is its perm rating. A vapor barrier may be defined as Class I or Class II (This definition was developed in Canada by the Canadian Standards Association or CSA). If the perm rating of the material is equal to or less than 0.25 perms, it may be considered a Class I vapor barrier material. If the rating of the material is equal to or less than 1.0 perm but greater than 0.25 perms, it may be considered a Class II vapor barrier material. Many materials have a perm rating less than 0.25, for example, 6 mil polyethylene film, aluminum foil, 3 coat of alkyd base paint, glass, metal sheet etc. Many materials have perm ratings greater than 1.0 and are not considered vapor barrier materials. These may include glass or mineral fiber insulation, fiberboard sheathings, spun bonded polyolefin building wrap or standard gypsum board.

If a sheet of polyethylene film is used to limit the vapor diffusion across an exterior wall exposed to a high outdoor summer temperature and humidity of 90oF and 62% Rh, from an indoor air conditioned space of 75oF and 50% Rh, the diffusion rate of outdoor water vapor to the indoor side of one square foot of polyethylene film, 0.06 perms, over one month would be approximately 44 grains (0.1 oz) of water vapor. This is an insignificant amount. However, if the same conditions were applied to a standard unpainted gypsum wall board finish having a perm rating of 50, the amount of water diffusion would increase substantially to 36000 grains (5.1 lbs) of water vapor. The need for a vapor barrier is governed by many factors which include the potential for condensation within a wall cavity, the potential for wood moisture content increase and wood rot, the needs for indoor dehumidification and air conditioning loads.

Position of the Vapor Barrier

The vapor barrier should always be placed on the high (humidity) vapor pressure side of the exterior wall. This is the exterior side for buildings in the south and the interior side for buildings in the north.

For buildings geographically located in areas where the indoor and outdoor vapor pressures are nearly equal, there is no need for a vapor barrier as the concentration of water vapor in the construction cavities will eventually reach the indoor and outdoor humidity conditions. However, if the day/night cycle of the area causes a significant difference in temperature between one side and the other or if a masonry cladding is wetted and solar heated frequently, it may be prudent to install a vapor barrier on the side of the wall cavity or insulation which is wetted most frequently while ensuring that rain penetration moisture does not become trapped in a cavity with vapor barriers on both sides or without drainage openings.

Psychrometrics of Condensation

Condensation occurs in a wall cavity when the temperature of one or more of the cavity surfaces falls below the dew point temperature of the cavity air. The dew point temperature of any mass of air may be determined from tables or from a psychrometric chart. For example, the dewpoint temperature of air at 90oF and 65% Rh is 77oF. If the air of a wall cavity is warm and humid as noted and if it encounters the inside surface of a vinyl covered gypsum board finish at 74oF due to the air conditioning of the room, condensation will occur in the wall cavity. If the wall cavity is protected by a vapor retarder and the exterior wall is air tight, the total condensation may be small from diffusion only. Condensation resulting from moisture transfer by diffusion may be determined by computing the temperature gradient and surface temperatures, the saturation vapor pressure at each surface and by computing the vapor flow through from the actual vapor pressures and the vapor flow resistance of the materials making up the exterior wall. Various methods are described in the ASHRAE Handbook of Fundamentals 2004 or they may be obtained as computer programs. Vapor retarder technology is now well developed. However, from the early sixties and on, building scientists and researchers observed that there were many successes with respect to moisture control for wall cavities but there were also baffling failures. It was soon discovered that water vapor could also migrate through exterior walls by the flow of air (mass flow) from one side to the other.

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In fact, it was soon realized that moisture migration by the mass flow of air (air leakage) could transport hundred of times as much water vapor as could be transported by diffusion though building materials. This revelation led to the development of a new requirement, specifically the need for an air barrier system for exterior walls and roofs of buildings.

Air Leakage and Air Barriers

In the early sixties, Neil B. Hutcheon, a researcher of the Division of Building Research (now the Institute for Research in Construction) of the National Research Council of Canada (DBR/NRCC), discovered that condensation in exterior wall cavities occurred primarily because of air leakage and specifically the exfiltration of humid indoor air. In 1977, G.O. Handegord, also of the DBR/NRCC concluded in a paper entitled “The need for Air-Tightness in Buildings” that air leakage is the principal means by which water vapor moves to cold surfaces and the major cause of condensation in buildings. In 1985, Rick Quirouette, also a researcher with the DBR/NRCC explained the difference between a vapor retarder and an air barrier and developed the fundamental design criteria for air barriers in the building envelope. At about the same time, the National Building Code of Canada (NBCC) introduced a separate and distinct air barrier requirement, Article 5.3 of the 1985 edition of the NBCC.

Air leakage is the passage of unfiltered, unconditioned unregulated outdoor air through the exterior walls and windows of a building to the inside (infiltration) or the uncontrolled leakage of indoor air through the exterior walls and windows to the outside (exfiltration). It occurs when there is a continuous passage, (openings, cracks, joints and paths) from one side of an exterior wall to the other and there is an air pressure difference across the exterior wall, window or roof. The rate of air leakage through an exterior wall, window or roof is governed by the size of the opening or cross sectional area of the path and the magnitude of the air pressure difference across the building envelope. Moreover, it is the humidity of the air which leaks in or out of the building and the duration of the air pressure difference which determines the type of problem which may occur as a result of the sustained air leakage.

Holes, Openings and Air Leakage Paths

The leakage of air through an exterior wall may leak through numerous types of holes, openings or air leakage paths. For example, it may infiltrate into an exterior wall at the weep holes of a brick cladding, through the imperfections of the brick ties and into the insulation cavity to exit into a room from an electrical outlet or from under the gypsum board finish and carpet at the exterior wall. Alternately, it may infiltrate through imperfections of a window frame or sill into a wall cavity and into a partition to deposit moisture as condensation on an air conditioned wall finish. In these examples, it is difficult to estimate the effective cross sectional area and the flow path length but it is certain that air leakage will occur and that condensation may accumulate in the exterior walls, floor cavities and partitions during hot and humid summers.

The leakage of air through a wall or roof must occur through an opening, hole or path from one side to the other. Openings, holes or leakage paths may be classified as direct, diffuse or channel.

A **direct opening** is usually characterized as a hole, crack or joint through which you can see to the other side. The flow path is short and direct. In this case the leakage of air may pass directly to the outside (exfiltration) to cause a loss of cooling energy. In the reverse direction, (infiltration), warm humid air may enter a building directly to raise the room temperature and humidity and to cause an overload of the air conditioning system.

Diffuse air flow is characterized by the screen effect whereby air permeates through the body or surface of a construction material to pass from one side to the other. For example air may be forced to pass through a concrete block wall, glass fiber insulation, some building papers and fiberboard sheathing.

Channel flow is the most common type of opening or leakage path. It is characterized by a tortuous path from an opening on one side to an opening on the other side. Paths of this type include air leakage into outlets, wiring holes, the base of gypsum board finishes, through a cladding vent hole, along steel deck flutes and numerous other flow path examples. Some openings or leakage paths may develop after construction because of the differential shrinkage of lumber as it dries out, the thermal expansion and contraction of cladding elements, or the deflection of sheathing and other panel types under wind load. at the entrance or exit openings of the leakage path,

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Channel air leakage paths are the most difficult to find. When they are found they are usually sealed

Air Pressure Difference

There are three principal sources of air pressure difference in buildings. These are stack or chimney effect, wind and ventilation systems. The net air pressure difference across a wall or roof may be a combination of all three and it may vary from one location of the building envelope to the other. The magnitude of this difference can also vary considerably depending on the shape of the building, the exposure, the height and local conditions of outdoor temperature and humidity.

Stack effect is a condition which occurs in all buildings in summer and in winter. It is the tendency for a mass of air at one temperature (building air volume) to rise or fall in another mass of air at a different temperature (the outdoor air). In summer, the tendency is for building air to sink down and out of buildings. This results from the difference in density of the indoor and outdoor air which generally causes a slight inward pressure at the top of a building, while exerting a slight outward pressure at the base. As a result, outdoor air tends to infiltrate at the upper levels of the building while exfiltrating at the lower levels. In a building where the air pressure difference at the exterior wall reverses from an inward pressure to an outward pressure and the pressure difference across the exterior wall diminishes to zero, the height within the building where this occurs is referred to as the neutral pressure plane (Npp). In winter the pressure patterns are reversed.

Typically, the stack effect pressure difference at the top of a reasonably air tight 10 storey building, approximately 98 feet high, with a neutral plane just above the 1st storey, approximately 10 feet above grade, will be approximately 0.3 lb./ft2 of negative air pressure difference (inwards) at the roof surface when the outdoor temp is 90oF and the indoor air is 75oF. This pressure difference is sustained against the roof and exterior walls as long as the temperature difference remains and the air leakage through the building envelope remains small. As the outdoor temperature changes, the stack effect pressure also changes. It becomes smaller as the outdoor temperature cools and falls to a lower level and reverses when the outdoor temperature drops below the indoor temperature. The stack effect pressure difference at the exterior wall is also a function of the ratio of the building envelope air leakage to the inter-floor air leakage (draft coefficient) rate. Generally, because the building envelope is many times tighter than the inter-floor leakage, (open stairways, elevator shafts, service shaft, etc.) the actual and the calculated stack effect air pressure difference on the outside walls are almost the same.

Wind pressure occurs on a building when the wind stagnates at the surface of the facade.
When the wind impinges on a building, it causes an increase in air pressure on the windward side of the building or facade and a decrease in pressure on the leeward and sides of the building. Similarly a flat roof will generally experience a decrease in pressure (or uplift pressure) induced by the wind washing over the roof surface. When wind is blowing at a building surface, some of the wind will penetrate (infiltrate) to the inside on the windward side while some of the indoor air will escape (exfiltrate) to the outside on the leeward and sides of the building and possibly from the roof surface. As the air leaks in and out of the building, the indoor pressure rises or falls until an equilibrium is reached between the total infiltration and the total exfiltration. The indoor pressure is the resultant of the balance of the air infiltration and exfiltration. Generally, the indoor pressure falls slightly with respect to the outdoor ambient pressure as wind passes around and over a building.

Wind produces the largest air pressure differences on the exterior walls and roofs of a building. It is not unusual to select a wind pressure base load of 15 to 30 lbs/ft2 for most buildings in the United States. Wind gusts can be 2.5 times higher than the base load. While the cladding and exterior walls are expected to support this load, it will be the air barrier system which will support the majority of the base load if it is continuous and air tight and the exterior cladding is vented to the outside. However, for the air barrier to resist such loads, it must be strong and structurally attached. Wind loads can displace air barrier membranes or cause materials to rupture and leak permanently.

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Fan pressurization. Ventilation air for a building is provided by fans. They are usually called upon to introduce, exhaust and circulate the air in a building. The fresh air and exhaust fans may be set negatively (exhaust greater than fresh air) to depressurize the building. This configuration is provided in many small commercial buildings including medium to high-rise buildings to minimize exfiltration of air conditioned air. Ventilation fans produce a small but significant air pressure difference across the building envelope. This air pressure difference must be considered during the design of the building envelope. Since the building requires an air barrier system, the HVAC designer must be advised that ventilation balance must not only include consideration of the mass flow balance of the air within the building but also consideration of the building pressure balance if the fresh air and exhaust air are not equal. Unusually low building pressures due to ventilation system design and operation may become problematic with respect to condensation problems in exterior walls, roofs and indoor partitions. The condensation is produced by the infiltration of outdoor air through minor discontinuities in the air barrier system from the resultant building depressurization or exhaust only systems.

Air Barrier Design Criteria

An air barrier system must meet four (4) requirements. These are continuity, air impermeability, strength and durability.

Continuity requires that the air barrier of a wall must be continuous with the air barrier system of a roof, window or below grade components. This continuity need not be achieved by the same material, however each material required for the control of air leakage must be connected to the other into a continuous plane of air tightness. For example, the air barrier of the roof must connect to the air barrier of the exterior wall usually in the parapet assembly.

Air Impermeability means the air barrier materials and system must be virtually air tight. Typically an air barrier system should not leak in excess of 0.06 cfm/ft2 at 1.57 lbs/ft2 air pressure difference for air conditioned buildings (rate used for curtain walls in commercial buildings). To achieve this level of performance for the system, a designer must choose materials with an air permeability rating that is less than 0.01 cfm/ft2 at 1.57 lbs/ft2 of air pressure difference.

This data is now available for many typical construction materials in the ASHRAE Fundamentals 1997 or from various Canada Mortgage and Housing Corporation (CMHC) Research Reports. This rating is measured using a test procedure known as ASTM E-283 and a pressure enclosure capable of receiving samples of construction materials measuring approximately 10 ft2. By applying a pressure difference across the sample and repeating the test several times in both directions at varying pressure differences, the leakage of air through the sample is measured and reported as the air permeability, usually in cfm/ft2 at 1.57 lbs/ft2.

Strength means the air barrier system must be attached to a supporting structure and it must resist excessive deflection, cracking, rupture or pull-through at fasteners. The air barrier system must withstand the highest expected air pressure load, usually wind, inward or outward, without detaching from its support. It must also resist peak wind loads, a sustained stack effect or a sustained pressurization load without exhibiting creep load failure (gradual unbonding of a membrane from its support).

Durability requires that an air barrier system and its components be designed and constructed to perform their intended function for the life of the building but more particularly the life of the building envelope. It must be made of strong and robust materials with adequate resistance to various environmental loads. Alternately, it must be positioned in the building envelope so that it may be serviced as required or maintained at a reasonable cost.

The Air Barrier System

The air barrier system must be an integral part of the exterior wall, windows and roof of the building envelope. It is not the combination of materials comprising these assemblies that is the air barrier system but rather it is a specific material plane within the roof, exterior wall or window designated to perform the tasks

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of the air barrier in each assembly is the air barrier system but rather it is a specific material plane within the roof, exterior wall or window designated to perform the tasks of the air barrier in each assembly.

For example, the concrete of a cast in place concrete exterior wall having insulation and a metal cladding may be designated as the air barrier component of this exterior wall. This is because the concrete is continuous, air impermeable, structurally adequate and durable. Similarly, an exterior sheet of metal with a peel and stick membrane over the joints and the whole fastened to a steel stud frame may be designated the air barrier system of the exterior wall for the same reasons noted above.

However, a polyethylene film on the outside of a steel stud system over glass fiber insulation is not suitable as the principal component of an air barrier system. This is because it is too fragile, the continuity is difficult to achieve at penetrations and joints but more importantly because there is inadequate structural support of the polyethylene film against wind pressure deformations. However, it is perfectly suitable as a vapor retarder. The air barrier function of the exterior wall must be joined with the air barrier function of the roof. This is sometimes difficult to achieve correctly particularly if the function of the vapor barrier is confused with the function of the air barrier. For example, the waterproof membrane of a roof is most likely to perform the function of the air barrier as it must also be impervious to rain penetration. In this type of building envelope, the roof membrane (air barrier) must now be connected to the exterior wall air barrier (perhaps the concrete of a shear wall). However, because most exterior walls of commercial buildings terminate in a parapet, the exterior wall air barrier must extend to the roof membrane or the roof membrane must extend to the exterior wall air barrier.

An air barrier system for the building envelope is not an option. It is the necessary assembly of the building envelope designated to limit and prevent excessive air leakage. It must be designed using robust materials, placed in a protected part of the roof or exterior wall or made accessible for maintenance and repair.

Air and Vapor Barriers

The function of the air barrier and the function of the vapor barrier are sometimes confused. It is important to note that there is a significant and important difference between these two functions and between the materials and systems providing these functions. However, it is also noted that these functions may also be provided by a single material or system providing the functional differences are well understood and the materials properties are selected accordingly. Specifically, an air/vapor barrier material or air/vapor system must exhibit a low air permeability to resist the passage or air from an air pressure difference and a low vapor permeance to resist the passage of water vapor by diffusion when it is subject to a difference in absolute humidity between one side and the other.

In a building envelope design where both functions are to be provided by a single material, the plane of the air/vapor barrier materials must be on the outside (or high vapor pressure side) of the building envelope insulation for most types of buildings in the southern Unites States. If the air and vapor barrier functions are to be located at separate locations, the vapor barrier function and material must be installed on the high vapor pressure side of the wall or roof while the air barrier function and material may be placed anywhere in the wall or roof system. However, when the air barrier function is placed inside of the insulation plane, the air barrier material or system selected must be permeable to water vapor to allow residual cavity moisture to diffuse to the indoor side for eventual dilution and exhaust by the indoor air and ventilation systems.

Conclusions

The need for air and vapor barriers in the exterior walls of buildings in the southern United States is imperative. To effectively limit condensation in wall cavities and therefore mold and mildew problems, to reduce rain penetration problems, to conserve cooling energy and to diminish design cooling capacity, the exterior walls of all types of buildings should incorporate both a vapor barrier and an air barrier system.

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The technology of vapor retarders is well developed. It may be included in the exterior wall as the cladding, the sheathing or a low perm membrane material on the outside of the insulation layer of the exterior wall. The principles of vapor retarder design must include the following requirements: (1) the vapor retarder should be continuous; (2) it should be vapor impermeable, 0.25 perms or less and (3) it must be placed on the high (humidity) vapor pressure side of the exterior wall. A Class I vapor retarder is best and suitable for all air conditioned buildings. A Class II vapor barrier should be installed on all other buildings if only to limit the diffusion of outdoor moisture into exterior walls and to avoid potential condensation problems due to temperature variations of indoor surfaces from night cooling ventilation and indoor temperature lag in the daytime. If an exterior wall has an outside vapor retarder, it should have a vapor permeable indoor finish to allow drying of residual moisture by indoor ventilation.

To effectively limit the condensation of outdoor humidity in exterior wall cavities by the leakage of high humidity outdoor air into air conditioned buildings, the exterior walls and windows must include an air barrier system. The principles of air barrier design are slightly more complex than vapor barrier design but they must include the following requirements: (1) the air barrier must be continuous; (2) it must be structurally supported; (3) it must be air impermeable and (4) it must be robust and durable. If the air barrier material is also vapor impermeable, it should be placed on the outside of the insulation layer for buildings in the southern United States, otherwise it may be placed anywhere in the wall assembly. The permeability of air barrier materials should not exceed 0.01 cfm/ft2 at 1.57 lbs/ft2 and the air permeability of the air barrier as a system should not exceed 0.06 cfm/ft2 at 1.57 lbs/ft2. All state energy codes and model building codes in the United States require building envelopes to be airtight by caulking and sealing but they are non-specific with respect to methods of air tightness or the amount of air leakage permissible. Until individual state building codes include a requirement for an air barrier, such as the Massachusetts Building Code, the design of air barriers for exterior walls is not mandatory. However, on the basis of mold and mildew control, rain penetration control, cooling energy savings and better indoor temperature and humidity control an air barrier is an indispensable feature of 21st century buildings.

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Rick Quirouette, B. Arch. is a building envelope specialist providing services to owners, professionals and manufacturers. As a graduate architect, he acquired 14 years of experience with the Division of Building Research of the NRC, 6 years of experience with Morrison Hershfield Consulting Engineers Ltd. and he is now operating his own firm Quirouette Building Specialists Ltd. since October 1993. His investigative skills and research and development experience are often the focus of a seminar, workshop or clinic. He is an accomplished lecturer and author. He is also a past president of the National Building Envelope Council of Canada.

Jacques Rousseau is an expert on airtightness and rain penetration. He retired from CMHC where he pioneered the popular Building Technology Seminar Series, designing seminars for architects, engineers and builders on topics such as air barrier, rain penetration and noise control technologies, computer assisted envelope design, and renovation strategies for highrise buildings. He was a director of the Building Environment and Thermal Envelope Council in Washington DC. He is a founding member of the BECOR and the OBEC. He is a fellow of the Ontario Building Envelope Council. But more importantly he is the editor of the Building Envelope Forum.