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The Difference Between a Vapour Barrier and an Air Barrier

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ABSTRACT

Moisture problems in walls have been attributed in large measure to two mechanisms: vapour diffusion, and now more importantly, air leakage, specifically the deposition of moisture by moist air exfiltrating through the building envelope. While significant technology related to vapour diffusion control (the vapour barrier) exists (i.e. calculation procedures, regulatory requirements, material standards and performance testing procedures), there is minimal technology available related to air leakage control (the air barrier) for the repair of existing building envelopes and virtually none for the design and construction of the envelope of new buildings.

This paper presents a definition of the air barrier, outlines the performance requirements, and examines the application of the theory to several typical commercial constructions. This application could provide a functional and durable air barrier within the building envelope.

RÉSUMÉ

Les problèmes d'humidité dans les murs ont été attribués en grande partie à deux phénomènes : la diffusion de la vapeur et celui, plus important, des fuites d'air (notamment par dépôt de l'humidité contenue dans l'air qui s'échappe de l'enveloppe d'un bâtiment). Bien qu'il existe des techniques pour contrôler la diffusion de la vapeur d'eau (pare-vapeur, méthodes de calcul, exigences imposées par les règlements, normes applicables aux matériaux, méthodes d'essai), il n'existe que très peu de moyens pour remédier aux fuites d'air (étanchéité à l'air) des enveloppes des bâtiments existants et à peu près rien pour la conception et la construction de l'enveloppe des bâtiments neufs.

Cette communication présente une définition du pare-vent, décrit les exigences relatives à sa performance et examine l'application de la théorie à divers types de constructions commerciales. Cette application pourrait permettre d'obtenir un pare-vent fonctionnel et durable à l'intérieur de l'enveloppe du bâtiment.

INTRODUCTION

A continuing examination of the performance of buildings in Canada has convinced the author that air leakage is the leading cause of exterior wall problems. It has been linked to efflorescence, spalling masonry, ice build-up under the soffits, frozen pipes and condensation in cavities, as well as rain penetration, high energy costs, and poor control over the indoor humidity conditions. Many of these problems originate early in the building process — during the working drawing and specification phases — and not with the materials used or the methods of construction, as was initially expected. The principal cause appears to be a major confusion concerning the function of the air and vapour barriers.

It is common architectural practice to specify a vapour barrier. Sometimes an air/vapour barrier will be specified, and on rare occasions the term "air barrier" may be used. This shows a lack of consistency in the use of these terms but, more important, shows a confusion in the industry about the design, materials and methods of construction of these fundamental components of the building envelope. However, the basic confusion is with the functions of these different barriers.

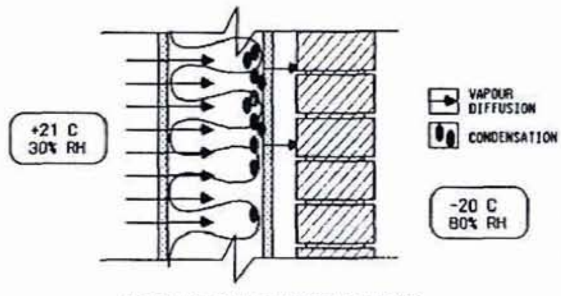
A 4 mil polyethelene sheet will make a good quality vapour barrier and twelve inches of cast-in-place concrete will make a good quality air barrier. This would be too restrictive a definition, but the functions of these two barriers are as different as polyethylene and concrete.

In practice many materials can be used as effective vapour barriers and many may be effective air barriers. The choice of materials or combination thereof and the method of assembly, are dependent on the function. A clear understanding of the functions of the two types of barriers is imperative to good design, and to effective and predictable building envelope performance.

VAPOUR DIFFUSION CONTROL (THE VAPOUR BARRIER)

The principal function of a vapour barrier is to stop or, more accurately, to retard the passage of moisture as it diffuses through the assembly of materials in a wall.

Diffusion is the process by which water vapour migrates through a material (Figure 1a). The rate at which water vapour migrates - or diffuses - depends on two factors: the difference between the water vapour pressure in the air inside the building and that in the outside air, and the resistance that materials present to the migration of moisture by diffusion.



WALL WITHOUT A VAPOUR BARRIER

FIG. 1A

All materials have a resistance to moisture diffusion, some more than others. Water vapour migrates through air, polyethylene film, fibre board, concrete and many other materials, but at varying rates. A vapour barrier is a material that offers a higher resistance to the diffusion of water vapour than most other materials. It is usually placed on the warm side of the insulation (Figure 1b). Polyethylene film of sufficient thickness is the material most commonly used for this purpose; however, other materials such as aluminum foil, some paint products, some insulation adhesives (mastics), metal, glass, and even concrete of sufficient thickness may be quite suitable as vapour barriers.

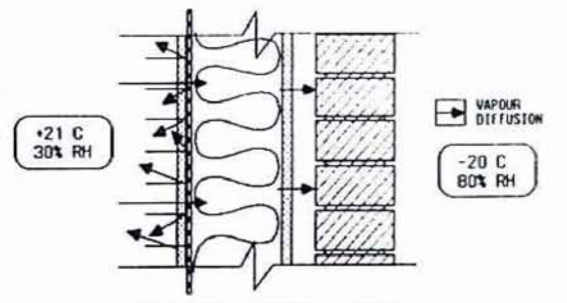


FIG. 1B

The moisture diffusion control property of a material is called its "water vapour permeance". This is usually expressed as the weight of moisture that will diffuse through a given area and thickness of material, over a specified period of time at a unit vapour pressure difference. For example, a sheet material, 0.1 mm thick, having a water vapour permeance of 10 will allow 10 nanograms of moisture to pass through one square metre of the material per second when the difference in water vapour pressure is one pascal. In practice, a maximum allowable rate of 15 is the accepted water vapour permeance standard (CAN 2-51.33-M80) for a Type I vapour barrier. Any material having a rating of 15 or less, may be suitable as a Type I vapour barrier, provided that it meets the other conditions of the standard.

For example, assume that the wall section in Figure 2 is a single stud space exposing to the room side one square metre of the vapour barrier. The barrier has a water vapour permeance of 5 $ng/Pa \cdot s \cdot m^2$ (0.087 $grains/h \cdot ft^2 \cdot in\ Hg$), the room conditions are 21°C, 30% relative humidity, while the sheathing is at −20°C. If these conditions prevailed for one month, approximately six grams of moisture would diffuse into the cavity. This would create only a thin layer of frost on the inside surface of the sheathing.

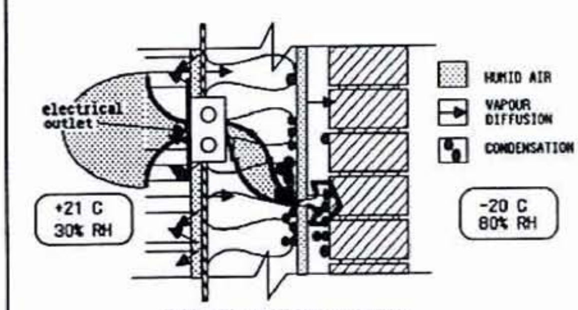


FIG. 2

This does not mean that diffusion control is unimportant and that the vapour barrier can be omitted. A vapour barrier is important, particularly in high humidity buildings such as computer centers, museums, hospitals, and public swimming pools.

For the vapour barrier to control condensation resulting from vapour diffusion it must be placed on or near the warm side of the insulation, which is normally the high vapour pressure side. Contrary to popular belief, a vapour barrier need not be perfectly continuous. Unsealed laps and pin holes, minor cuts, etc., do not increase the overall moisture diffusion rate into a wall or roof cavity appreciably. It is worthwhile, however, to avoid these imperfections if possible.

AIR LEAKAGE CONTROL (THE AIR BARRIER)

Water vapour diffusion is only one of the mechanisms by which water can be transported into a wall or roof cavity. The provision of a vapour barrier within the wall or roof assembly satisfies only part of the requirement of controlling moisture entry into building enclosures. The other mechanism, which is now considered to be far more significant, is air leakage. Air leakage occurs when openings (holes, cracks, etc.) in the building envelope form a continuous path from inside to outside and an air pressure difference occurs across it. Both mechanisms may, of course, operate at the same time.

The principal function of the air barrier is to stop outside air from entering the building through the walls, windows or roof, and inside air from exfiltrating through the building envelope to the outside. This applies whether the air is humid or dry, since air leakage can result in problems other than the deposition of moisture in cavities. Exfiltrating air carries away heating and cooling energy, while incoming air may bring in pollution as well as disable a rain screen wall system.

Moisture-laden air passing through an insulated cavity with a vapour barrier may deposit much more moisture than would diffuse through the vapour barrier in the same period of time.

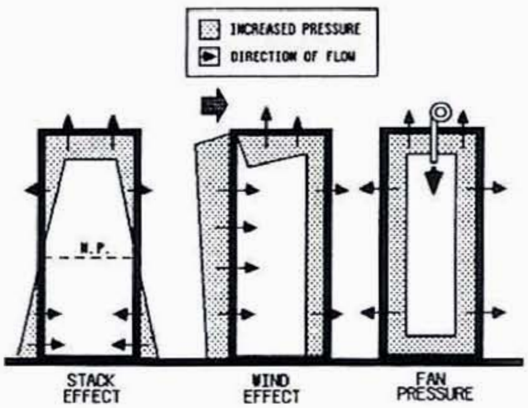
For example, if the room side surface in Figure 2 were opened to the cavity, perhaps through an electrical outlet or a service pipe penetrating to the inside, with a net opening area of 625 mm^2 (1 in^2), 2600 m^3 (91818 ft^3) of air would enter and exit the cavity to the outside under a 10 Pa (0.2 lbs/ft^2) pressure difference (equivalent to a 15 km/h (9.3 mph) wind) over one month. This would amount to approximately 3000 kg (6614 lbs) of air and 14 kg (30.9 lbs) of water. Assuming further that only 10% of this water condenses out in the cavity, then air leakage has deposited 233 times (10% of 14 kg, 1400 g/6 g) the amount of moisture that passed by diffusion only.

Air Leakage Paths

Holes or openings through the envelope can take many forms, for example: cracks or joints between infill components and structural elements, or poor connections between the wall and the roof and at openings for building services. They may occur even in porous materials, for example concrete block, high density glass fibre, open cell polystyrene insulation, and fibreboard. Some openings follow direct channels from inside to outside, as in an uncapped steel deck at the perimeter of a floor or ceiling. Others may appear on an inside surface finish (behind a radiator cabinet or above a suspended ceiling), leading into a wall cavity and on through holes at some other location in the outside finish, or as weep or vent holes in brickwork. Some openings may develop after construction because of differential brick or block movement, caused by shrinkage of mortar, thermal expansion and contraction of building elements, or deflection of beams. Other openings may result from an inappropriate choice of joint materials.

Air Pressure Difference

Air leakage through the openings in the building envelope is caused by air pressure differences from one or more of three sources (Figure 3). The first is the stack effect or the chimney effect, dependent on a temperature difference between the inside and the outside of a building. Second, a pressure difference may also be induced across the building envelope by wind forces acting on it. Third, the operation of ventilation equipment may produce a pressure difference. The net air pressure difference across a wall or roof may be a combination of all three, and it is not the same at all parts of the building envelope. The size of this difference can also vary considerably — from one to ten pascals (0.2 lbs/ft^2) in a small house, and periodically as high as 2000 pascals (42 lbs/ft^2) under the highest wind load, stack effect and fan pressurization conditions.



AIR PRESSURE DIFFERENCES ON THE BUILDING ENVELOPE

FIG. 3

Stack effect. The stack effect results from warmer inside air having a lower density than the cooler outside air. This difference in density creates a slight outward positive pressure at the top of a building, while exerting a slight inward negative pressure at the base. Hence, air will tend to infiltrate at the lower levels of the building and exfiltrate at the upper levels. Typically, this represents a 50 Pa (1 lb/ft^2) inside/outside air pressure difference at the roof line of a 25 storey building in mid-winter, assuming that the neutral pressure plane is near the middle of the building. Simultaneously, there will be a 50 Pa pressure difference at the lobby level which is acting inwardly. (This air pressure difference is often the reason why outward swinging doors are difficult to open at the lobby level of high rise buildings, and one reason for the use of revolving doors.)

Wind. Wind causes infiltration on the windward side of a building and exfiltration on the leeward side and on the sides parallel to the wind direction. Similarly a flat roof will generally have exfiltration because of negative pressure caused by wind. Since wind velocity increases with height, the difference in pressure across the building envelope also increases with height.

Pressure distribution on the windward façade varies from a maximum in the centre, diminishing towards the perimeter. Suction pressures, on the other hand, may vary from a maximum at the perimeter, diminishing towards the centre. The pressure on the side walls parallel to the wind is normally negative, but may change rapidly in value and even to a positive pressure as the wind changes direction.

If a window is opened on the windward side of a house, the interior pressure will rise and become almost equal to the pressure on the exterior wall facing the wind. The other walls and the roof, however, may undergo a substantial increase in air pressure difference, which in turn may substantially increase the exfiltration through the ceiling and the leeward wall of the building.

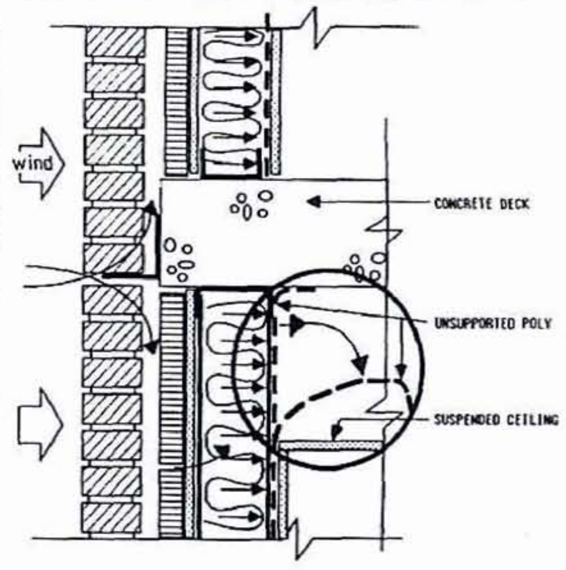
Fan pressurization. Ventilation air for a building is provided by fans. They may be as small as a bathroom fan for a dwelling or as large as a house for some types of commercial, industrial or institutional buildings.

Regardless of size, they are usually called upon to introduce or to exhaust air from a building. They may be set positively (supply greater than exhaust) to pressurize the building; this is done in highrise structures to minimize the air pressure difference at lobby levels caused by stack effect. They may be set negatively (exhaust greater than supply) to prevent any moist air from entering the roof or wall cavities by exfiltration; this could be done for an indoor swimming pool enclosure.

Ventilation by fans may produce a small but significant air pressure difference across the building envelope. This force should be recognized during the design of the building envelope, as some materials may be forced out at joints or come apart at seams under sustained pressures.

Structural Considerations of Wind Forces

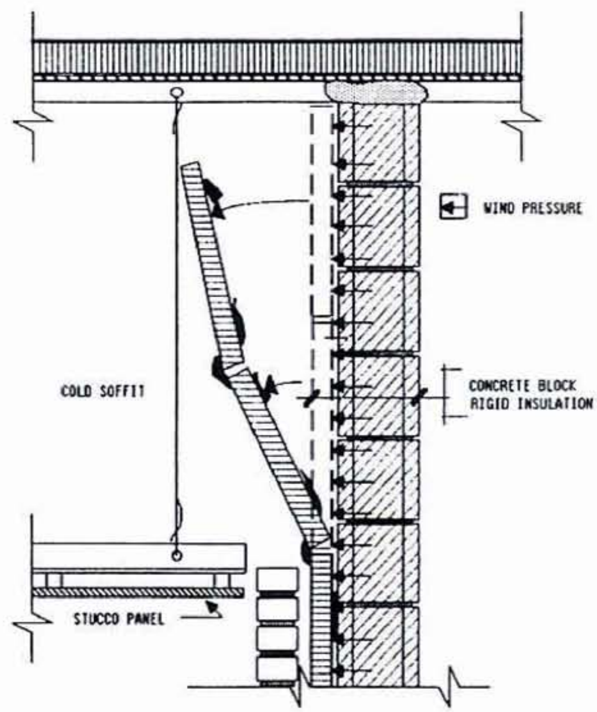
Occasional high winds may produce high pressure differences across a wall and put stress not only on the cladding but on those materials in the wall or roof cavity which have an inherent high resistance to air leakage (for example, concrete decks, roofing membranes, precast panels) or on those materials (the air/vapour barrier) that are designated to control air leakage. If the air pressure difference exceeds the capability of the air barrier system to support the load, then air tightness will be destroyed and a permanently increased air leakage will result (Figure 4). It is most important to realize that if an air pressure difference cannot move air, it will act to displace the materials that prevent the air from flowing.



WIND PRESSURE DISCONNECTS POLYETHYLENE FILM FROM DECK

FIG. 4

In a relatively new shopping center some of the insulation, attached by spot adhesive to a block wall, separated from the backup block and fell onto the soffit ceiling platform of the large overhanging roof (Figure 5). When wind action (a large door opened on the windward side) caused the building interior pressure to rise, the air pressure acting through the porous block wall apparently pushed the insulation with sufficient force to overcome the strength of the adhesive, resulting in the separation. This case illustrates the importance of pressure differences acting across the most air impermeable material, which may not be attached securely to the supporting structure and was not intended to stop air.



WIND PRESSURE DETACHES INSULATION FROM BLOCK WALL

FIG. 5

Each membrane or assembly of materials intended to support a differential air pressure load must be designed and constructed to carry that load, or it must receive the necessary support from other elements of the wall. If the air barrier system is made of flexible materials then it must be supported on both sides by materials capable of resisting the peak air pressure loads; or it must be made of self-supporting materials, such as board products adequately fastened to the structure. Some membrane products may be satisfactorily adhered to a solid substrate to form a composite air barrier system (membrane plus substrate), for example, a rubberized asphalt membrane applied to the surface of a masonry infill wall.

AIR BARRIER DESIGN REQUIREMENTS

Materials and the method of assembly chosen to build an air barrier must meet several requirements if they are to perform the air leakage control function successfully.

1. There must be continuity throughout the building envelope. The air barrier material of the wall must be continuous with the air barrier material of the roof (e.g., the roofing membrane). The air barrier material of the wall must be connected to the air barrier material of the window frame, etc.

2. The air barrier system must be fastened to a supporting structure to resist a peak wind load, a sustained stack effect or pressurization from ventilation equipment; it must be sufficiently rigid to resist displacement.

   a) The materials and configuration of the air barrier assembly must resist the highest expected air pressure load, inward or outward, without rupturing or detaching from the support.

   b) The assembly must not creep away from a substrate or part at a joint under a sustained air pressure difference (such as stack effect or fan pressurization).

   c) The deflection of the air barrier materials between supports must be minimized to prevent the displacement of other materials (such as insulation in cavities).

3. The air barrier system must be virtually air-impermeable. A value for the maximum allowable air permeability has not yet been determined. However, materials such as polyethylene, many single ply roofing membranes, gypsum board, cast-in-place concrete, metal or glass qualify as low air impermeable materials, whereas concrete block, acoustic insulation, open cell polystyrene insulation or fibreboard would not.

   The metal and glass curtain wall industry, notably in the U.S., has adopted a value of 0.3 $L/m^2 \cdot s$ (0.06 CFM/ft^2) at 75 Pa (1.57 lbs/ft^2) as the maximum allowable air leakage rate for these types of wall construction. This value however is considered high for buildings in Canada and some Canadian manufacturers of metal and glass curtain wall systems claim that their system will meet 0.1 $L/m^2 \cdot s$ or better for the same air pressure difference. However, even this may still be too high. It is not difficult to find material which has a leakage of practically zero. But, it is the total assembled air barrier system (main areas plus joints) which must exhibit practically zero leakage.

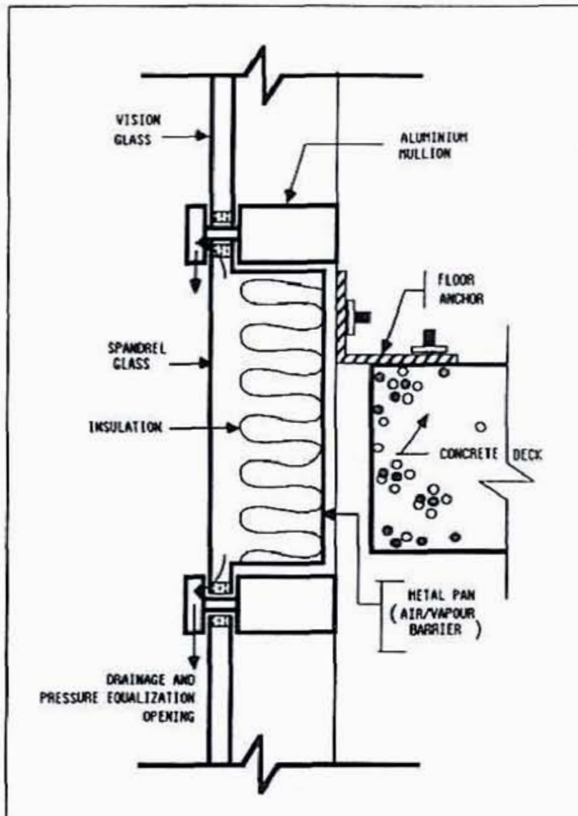
4. The air barrier assembly must be durable in the same sense that the building is durable, and be made of materials that are known to have a long service life or be positioned so that it may be serviced from time to time.

AIR BARRIER DESIGN APPLICATIONS

Combined Air and Vapour Barriers

A wall or roof assembly will require an air barrier and possibly also a vapour barrier. They may or may not be the same material. But a combined system must meet the design requirements for both functions.

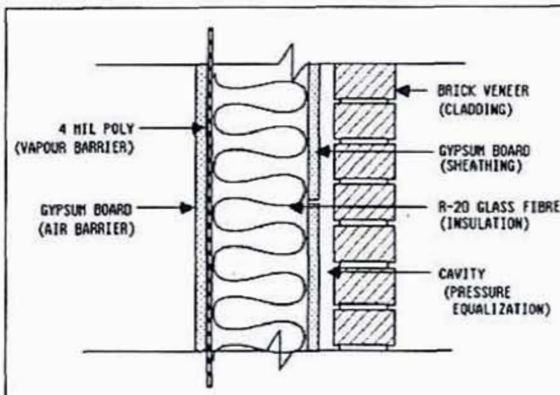
In the assembly shown in Figure 6, the theory of vapour diffusion control and air leakage control has been applied correctly within the metal and glass curtain wall systems. In this case the vapour diffusion control function and the air leakage control function are both met by the use of a galvanized sheet steel pan in the spandrel area of the curtain wall. The sheet steel is impermeable to moisture and it is positioned on the warm side of the insulated assembly. The sheet steel pan is also air impermeable. It is sufficiently strong, and is often made rigid by the use of intermediate stiffeners securely fastened to withstand the peak wind load pressure. Systems like this are often subjected to peak wind load air pressure tests. Because the steel pan is usually sealed at the perimeter of the frame opening, it is part of a continuous airtight system. It is also as durable as most other components of the wall.



COMBINED AIR AND VAPOUR BARRIER
FIG. 6

Separate Air and Vapour Barriers

Figure 7 shows a typical exterior wall consisting of brick veneer, an air space, an exterior sheathing, glass fibre insulation within a steel stud frame, polyethylene film and gypsum board. In this case the polyethylene is intended as the vapour diffusion control element. It meets the requirement of water vapour diffusion resistance for a Type I vapour barrier and is positioned on the warm side of the assembly. However, the design and the appearance of the wall depart from normal practice. The inside gypsum board is designated as the air barrier, rather than the polyethylene. The polyethylene would probably meet the air barrier requirements if it were adequately supported on both sides. In most cases, however, it is the low density glass fibre insulation which is used to support it on the cavity side. This support may not be sufficient for pressures due to high winds. Another difficulty is that there is no adhesive known that will form a lap joint with the same strength



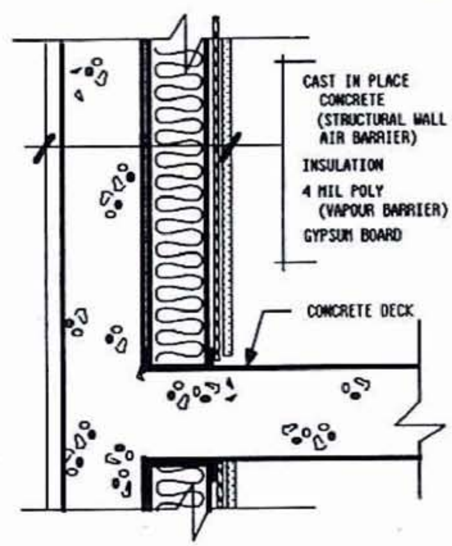
SEPARATE AIR AND VAPOUR BARRIERS
FIG. 7

as the polyethylene. The layer of gypsum board sheathing can meet all the requirements of airtightness if all joints are taped and a continuous air seal with other components of the envelope is provided. Although the gypsum board may not be as durable as sheet steel, it is accessible and therefore serviceable.

Position of the Air Barrier

A vapour barrier is usually placed on the warm side of the insulation. It may also be positioned part way into the insulation but, for satisfactory performance, it should be no further in than the point at which the temperature of the inside air drops to its dew point. While it is preferable that the air barrier system be placed on the warm side of an insulated assembly, it is not an essential requirement as it is with the vapour barrier. The position of the air barrier in a wall or roof is more a matter of suitable construction practice and the type of materials to be used. However, if this barrier is positioned on the outside of the insulation, consideration must be given to its water vapour permeability in case it should also act as a barrier to vapour which is on its way out from inside the wall assembly. This situation may be prevented by choosing an air barrier material that is ten to twenty times more permeable to water vapour diffusion than the vapour barrier material.

There are many situations in practice in which the air barrier of a wall or roof is on the outside of the insulation and performs quite satisfactorily. In the case of a typical medium rise apartment building, which has a decorative exposed cast-in-place concrete shear wall (Figure 8), the exterior facade is insulated on the inside. Further, it usually has a 0.1 mm (4 mil) polyethylene vapour barrier and a gypsum board interior finish. In practice, the cast-in-place concrete exterior wall is a continuous and structurally adequate air impermeable element of the wall and therefore acts as the air barrier. The vapour barrier is the polyethylene, and so long as it, the insulation and the interior surface of the concrete shear wall are in intimate contact, the wall will perform quite satisfactorily, as it has in many existing buildings. If the insulation is not in intimate contact with the concrete, convection within the cavity may seriously alter the thermal performance of the insulation. A prerequisite of any wall design is that the insulation be in intimate contact with the air barrier. But the general opinion among most researchers and practitioners is that the air barrier should be placed on the warm side of the insulation, where thermal stresses will be at a minimum. (Inside of the insulation does not necessarily mean on the inside surface of the wall.)



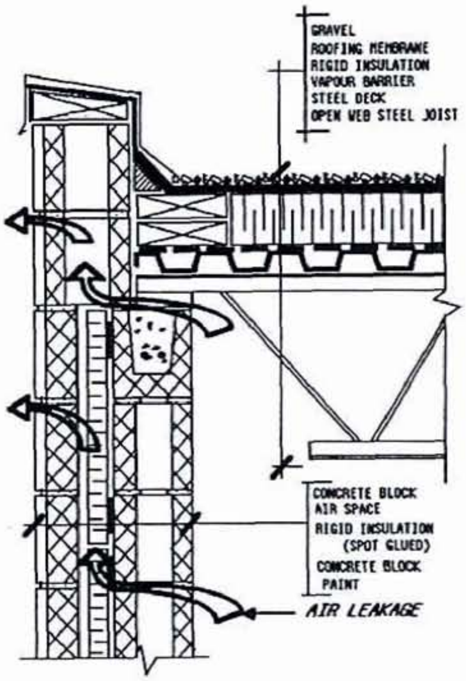
AIR BARRIER ON THE EXTERIOR

FIG. 8

Joint Design

While the discussion above has been concerned with the flat areas of walls or ceilings, the joints between them may well present the most important design and construction problems. There are many kinds of joints but for the purpose of this discussion the following are considered the most critical: the roof/wall connection, the wall/foundation connection, the wall/window or /door connection, soffit connections, corner details, and connections between different types of exterior wall systems, such as brick and precast, curtain wall and brick or precast, steel siding and curtain wall.

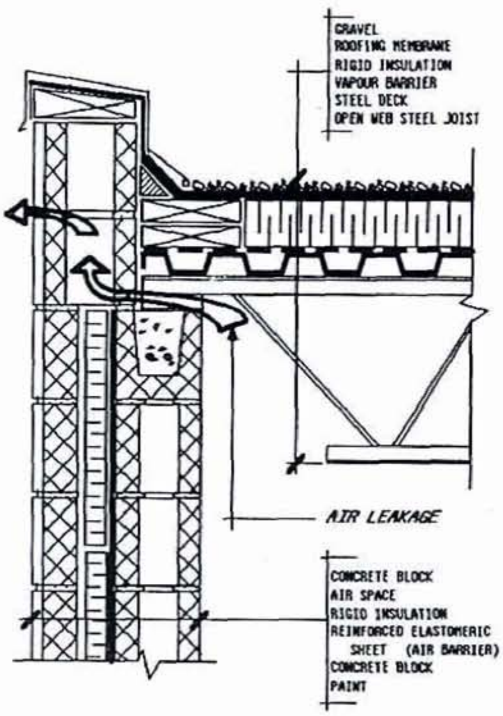
To illustrate one joint design problem, Figure 9a shows a wall/roof connection typical of many small commercial buildings. A steel joist rests on a load bearing block. The roof is composed of a conventional B.U.R. membrane over an insulation layer, which is over a vapour barrier fastened to a steel deck. The wall consists of a decorative exterior 100 mm (4 in) concrete block, and a 25 mm (1 in) cavity (air space), with a spot adheared insulation. As the air flow arrows indicate, this type of wall is subject to a serious air exfiltration problem through the block surface and joints, often resulting in spalled exterior block, icicles forming on the exterior surface, and rain penetration problems. No matter how well this wall section is built, its performance will not improve. It is the design that requires corrective measures.



AIR PERMEATES THROUGH BLOCK WALL AND LEAKS AT ROOF/WALL CONNECTION

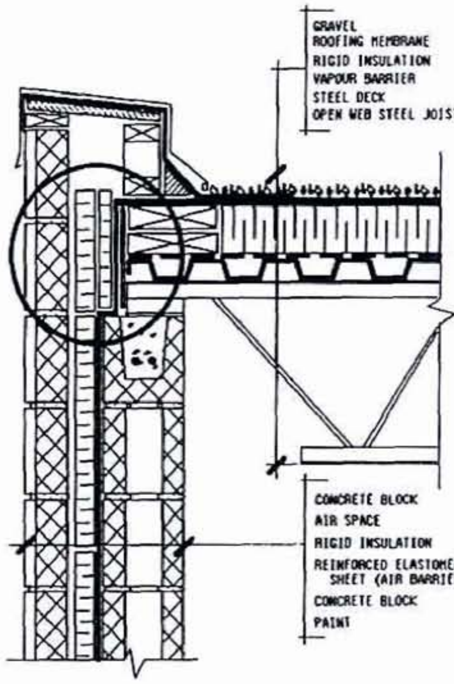
FIG. 9A

To correct the situation two design changes should be made. The first is depicted in Figure 9b. Since the wall is as permeable to air as a fly screen (through the joints between the blocks), an air impermeable plane must be built onto the block surface before the insulation is installed. The air barrier (an air impermeable material combined with a block wall), may be cement parging (questionable long term performance) or perhaps a board product fastened mechanically to the block wall with all joints sealed, or a reinforced rubberized membrane. Regardless of the materials chosen, the air barrier must be impermeable to air, able to support the peak pressure load, continuous from foundation to roof, and durable.



AIR LEAKS AT ROOF/WALL CONNECTION

FIG. 9B



ROOF MEMBRANE (AIR BARRIER) IS CONNECTED TO ELASTOMERIC SHEET (AIR BARRIER)

FIG. 9C

The insulation could be attached to the air barrier (which could also serve as a vapour barrier) followed by an air space and the block veneer. This design change brings a positive solution to the airtightness function of the wall.

The second design change involves the connection between the wall and the roof. In Figure 9c the 200 mm (8 in) parapet block has been replaced with a 100 mm (4 in) block, and the roof membrane (the air barrier) is fastened to wood blocking that is bolted to the steel deck. An air barrier material (preferably sheet steel or heavy roofing membrane) is then connected from the roof membrane to the air barrier material of the wall. The air barrier of the roof is now appropriately connected to the air barrier of the wall. The remainder of the components, that is, the insulation, the masonry, the cap and counter flashings are installed afterwards with the masonry and the insulation of the wall.

This joint design problem illustrates how airtightness control, vapour diffusion control, and thermal resistance continuity may be achieved at the roof/wall junction for this type of building, without altering the architectural lines of the roof or the appearance of the façade. It does not add significant cost to the construction process. Joint design must, of course, take into account the sequence of construction and the jurisdiction of the various trades.

CONCLUSIONS

The function of the vapour barrier is to retard water vapour diffusion into insulated building envelope assemblies. Vapour diffusion control is simple to achieve and is primarily a function of the water vapour diffusion resistance of the chosen materials and their position within the building envelope assembly. The barrier should be clearly identified by the designer and clearly identifiable by the builder.

Air leakage control is a more complex objective, which must be considered as a separate and distinct function for any wall, roof, window and especially joint detail, and even for the below grade portion of the building envelope. The function of the air barrier is to eliminate the through flow of air from inside to outside and vice versa. An air barrier must be continuous, be structurally fastened or supported to withstand a peak air pressure load, and be virtually impermeable to the passage of air. It must be durable or easily serviced. Again, it is important that the designer clearly identify the air barrier and that the builder recognize it as such. It is desirable, but not essential, that it be installed on the warm side of the insulation, so that thermal stability will be improved and access for future maintenance be assisted. The vapour and air barriers may or may not be the same material; if they are the same material, then it must meet all the requirements of airtightness control and of vapour diffusion control.

If the barriers are not the same material, then the vapour barrier material need only meet the requirements for vapour diffusion control and the materials designated for the air barrier need only meet the requirements for air leakage control.