THE MEMBRANE ROOF: THE ORIGINAL AIR BARRIER

DOUGLAS C. FISHBURN
Fishburn Roofing Sciences Group Ltd.
Hornby, Ontario, Canada

Air leakage in buildings wastes energy and can negatively impact the function and durability of construction products. The use of an air barrier to control air leakage is considered a relatively new technology. Roofing systems, such as built-up roofs have, however, served this function successfully for more than 100 years.

Roofs today are typically designed and constructed with high levels of thermal insulation and from a wide variety of new materials. The performance characteristics of these newer materials places a greater emphasis on the control of air leakage, particularly with gravel-ballasted and mechanically fastened roofing systems.

Damage from condensation, wind-driven gravel ballast, and dislodged membranes are only some of the problems encountered with uncontrolled air leakage. Control of air leakage will reduce significantly the forces acting on the membrane while minimizing the impact contributing to many roof problems.

The contents of this paper will review the impact of air leaking upon the function and performance characteristics of roof systems and examine how these forces can be neutralized with proper design and installation of an air/vapor barrier.

KEYWORDS

Air barrier, air leakage, air/vapor barrier, mechanical pressurization, roof assemblies, roof membranes, stack effect, wind.

INTRODUCTION

Over the past few years, few other subjects have captured as much attention and interest in the construction industry in Canada as the air barrier. Typically, the attention has been focused on wall type air barrier systems with particular emphasis on materials and their continuity at openings such as doors, windows, and roof-wall junctions.

While air barrier technology may appear to be a relatively new subject, the destructive forces of moisture carried by air leakage have been intensively studied for more than twenty years. It is also seldom realized that air barriers are not new to the construction industry, because bitumen roofing has been providing this function on low-slope roofs in Canada for more than one hundred years, with great success. In fact, most membrane air barrier systems used in masonry wall construction today have been adapted from roof membrane technology.

While the primary purpose of the roof is to provide water tightness, changes in construction practices and the evolution of roof material systems over the past 25 years has required the roof membrane to serve multiple functions.

Although it is recognized that vapor retarders protect a roof from vapor diffusion from below, studies completed by NRC (National Research Council) in a publication entitled *Moisture Considerations in Roof Design* showed significantly higher levels of moisture occurring in roof assemblies than can be accounted for by vapor diffusion alone. It was concluded that this difference was due to air leakage.[1]

The lack of airtightness allows interior moisture to bypass the vapor barrier and is one of the prime causes of condensation problems.

Air leakage can be controlled by the use of an air barrier; however, for all practical purposes, the vapor barrier in most roof assemblies provides this function. It is, therefore, more appropriate in conventional roof assemblies (membrane above the insulation) that the vapor barrier and air barrier function be combined and the term air/vapor barrier (AVB) be employed. A separate air/vapor barrier is not required in a protected membrane roof assembly (membrane below insulation) since the roof membrane in conjunction with the deck and gypsum or cement board underlay typically provide this function.

The protection of the building envelope, including the roof, from air leakage was first introduced in the 1975 National Building Code of Canada (NBC); however, a separate air barrier requirement originally appeared as Section 5 of the 1985 NBC, which stipulates the use of an air barrier for the control of air leakage.[2] The requirement for an air barrier remained unchanged in the 1990 NBC, which reads partly as follows:[3]

Section 5.3 Control of Air Leakage
5.3.1 Air Barriers
5.3.1.1. Locations
(1) Where a building assembly will be subjected to a temperature differential, a differential in water vapor pressure and a differential in air pressure due to stack effect, mechanical systems or wind, the assembly shall be designed to provide an effective barrier to air ex-filtration and infiltration, at a location that will prevent condensation within the assembly, through:
(a) the materials of the assembly,
(b) joints in the assembly,
(c) joints in components of the assembly, and
(d) junctions with other building elements.

Section 5 of the 1990 NBC has since undergone significant changes with the adoption of the 1995 NBC and addresses protection against wind, water and moisture vapor and is titled *Environmental Separation.*

Although the 1990 NBC specified that the air barrier was to be continuous and *effective*, the 1995 NBC qualifies effective by specifying a maximum air leakage rate of 0.02 $L/m^2 \cdot s$

(0.0005 US gallons/ft²·s) at an air pressure difference of 75 Pa (1.57 psf). This limit may be exceeded in some cases, providing there is a mechanism in place to prevent degradation of the building. The 1995 NBC is specific in that as part of the air leakage requirement, the wind loads must be transferred to the building structure, and the air barrier must be capable of resisting 100 percent of the specified wind load.[4]

GENERAL AIR BARRIER REQUIREMENTS

In order to be effective, the air barrier must consider four principal requirements:[5]

- resistance to airflow,
- structural soundness, capable of resisting loads imposed by wind, stack effect, and mechanical pressurization over its expected life span,
- continuity throughout the building envelope
- be durable over the assembly life span if concealed or at least accessible and easy to maintain over the building life cycle

The air barrier must be compatible with other materials with which it comes in contact and able to withstand the environment to which it will be exposed during and subsequent to construction.

The air barrier may be composed of a single material or component but is most often constructed using a number of components or materials. A thorough understanding of design principles and construction practices is required to ensure the compatibility and proper interconnection of materials incorporated as components of the air barrier in the building envelope. Ease of construction and reliability of material performance are crucial to the success of building envelope performance because future accessibility for assessment of problems and/or failure is limited and costly.

AIR LEAKAGE MECHANISMS

The principle of air leakage requires two conditions to be present in order for the leakage to occur. First, there must be a discontinuity or opening in the building envelope that will allow the passage of air. Second, there must be an air pressure difference across the building envelope, which generally results from a combination of wind effect, stack effect or mechanical pressurization.[6]

Although the roof subsurface components will restrict airflow, air leakage through the assembly to the underside of the membrane can result in ballooning or fluttering of the membrane on mechanically fastened or the ballasted single-ply membranes.

Although attention has been focused on the performance of individual roof components, such as membranes, insulations, vapor barriers, and decks, and how they behave as a waterproofing system, relatively little attention has been given to the subject of how these materials interact simultaneously in various roof systems with regard to the control of air leakage. The contribution of various roof components to the control of air leakage is clearly demonstrated by the fact that the NBC allows the design uplift forces on roofs constructed over concrete decks to be reduced 25 percent because of the monolithic nature and impermeability to airflow of concrete decks. Discontinuous decks, such as wood plank and metal, are not airtight and lack this design advantage.

Although a concrete deck may act to restrict airflow, a separate membrane such as two plies of felt and bitumen, is typically required to serve as an air/vapor barrier to protect against air leakage at hairline cracks, roof openings, and points of termination. In this regard, the concrete deck provides the structural integrity to resist the air pressure and uplift forces while the membrane air/vapor barrier provides the flexibility, compatibility, and continuity in order to accommodate the interconnection with the building airtight diaphragm.

On metal decks, the structural requirement to resist uplift forces can be provided by the installation of an overlay, such as cement board, which transfers the uplift loads to the metal deck using mechanical fasteners. The installation of a solidly bonded vapor retarder as stated for concrete decks would provide the requirement for continuity. In this installation, the cement board and vapor retarder act in unison to pro-

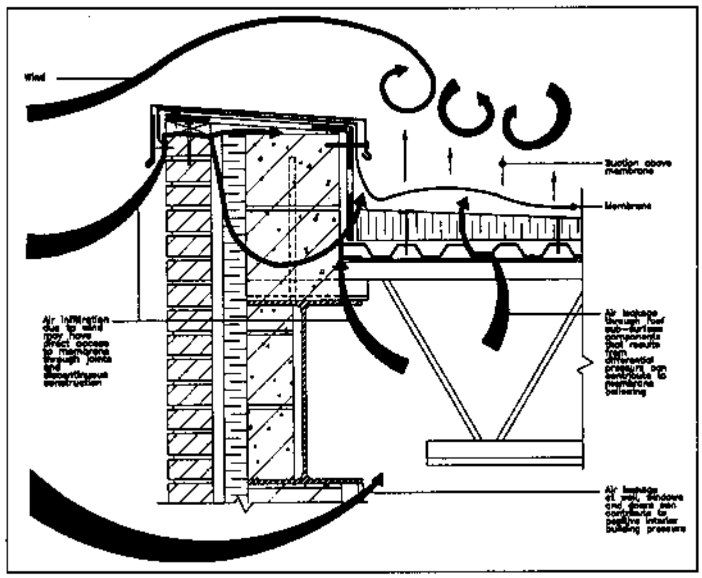

Figure 1. Shows effect of faulty air barrier.

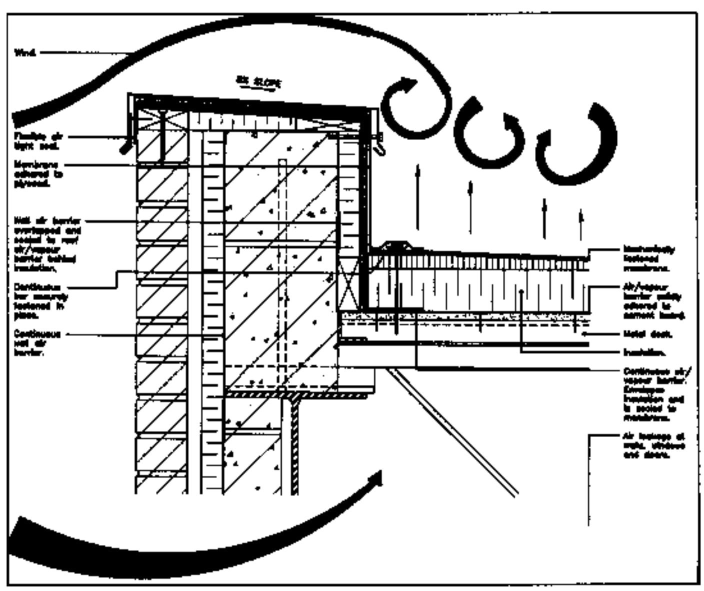

Figure 2. Shows properly constructed air barrier.

vide the air barrier requirement.

Providing the joints and points of termination are adequately sealed, a plywood deck should be adequate to resist air leakage. Wood plank decks may require an overlay to which a continuous vapor retarder, such as a self-adhered, torch- or mop-applied modified bitumen membrane or built-up membrane is installed. Alternatively, attachment of a base sheet secured with mechanical fasteners and capped with an additional ply of membrane adhered into place might also serve the function of an air/vapor barrier on wood decks. The installation of a properly designed and mechanically fastened, reinforced base sheet covered with one or more plies of felt and hot bitumen installed over an acceptable deck will also act as a barrier to airflow.

Unless roofing components become dislodged, under normal conditions, air leakage generally remains undetected except for increased energy costs. When the air has a high relative humidity, air leakage can have a major impact on building envelope performance if the air condenses within the building envelope.

Control of air leakage is especially important in freezer type building designs when the roof is used as part of the freezer enclosure. In this scenario, the thermal and moisture drives are reversed, with airflow taking place from the building exterior to interior.

The roof membrane in this environment not only functions as the waterproofing but also serves as the vapor and air barriers. Moisture from air leakage will quickly accumulate as ice, thereby increasing the live load on the structure. The cost of removing and disposing of insulation when reroofing freezer-type buildings is often unpredictable because of the difficulty in determining the weight of the insulation if it has become moisture-damaged.

In addition to moisture building up and accumulating within the roof assembly, failure to control air leakage can result in the buildup of icicles hanging from the underside of the roof deck and structure.

Figure 3. Photo shows icicles hanging from the deck and structure inside a freezer-type building. Investigation of this phenomena showed that the buildup of ice was due to air leaking at the roof-wall junction.

AIR LEAKAGE REQUIREMENTS VS. ROOF TYPES

In order to understand the role of an air barrier and the importance of airtightness, a review of basic roof design is required. The two basic roof systems that form the basis of this paper are the protected membrane roof system (membrane below insulation) and the conventional roof system (membrane above insulation). Roof systems can be constructed using a wide variety of membranes, including conventional bituminous, thermoset, thermoplastic, or modified bitumen roof membranes. Each system can be constructed using various materials and assemblies. An overview of the respective systems is as follows:

PROTECTED MEMBRANE ROOF SYSTEM

Generally, all membrane types may be used in a protected membrane roof (PMR). The membrane in this system not only provides the waterproofing but also acts as the vapor barrier. Whether the membrane provides or acts in concert with other building elements to provide an air barrier depends upon the type of deck or deck overlay and method of attachment to the substrate.

In addition, because the roof membrane base flashings form part of the envelope seal, they must also provide resistance to air and moisture flow as well as provide thermal continuity to offset condensation that can result in condensation traps.

If flashings and cant strips are left unprotected, these areas may be subject to moisture accumulation caused by vapor diffusion. Condensation traps can result in damage to materials due to their absorbing water, deformation by ice buildup and by fungus attack. Figure 4 shows wood decay at the roof perimeter that resulted from moisture diffusion and air leakage from below.

In order to prevent this occurrence, protection is required by such methods as underlaying all cant strips with an air/vapor barrier to seal the junction between the roof and wall. If cants are not employed, as in the case of most single-ply roofs, the sealing of the roof membrane to the wall could provide the air/vapor barrier function. The air/vapor barrier under any cants must be continuous and of sufficient strength and stiffness to accommodate the imposed air pressure loads and movement without failure.

Depending upon the type of building construction, the air barrier and vapor barrier may be constructed using a single material or combination of materials and can be located in the same or different positions within a roof assembly. As represented in Figure 5, which shows a parapet flashing, a properly designed and installed protected membrane roof can easily be constructed to fulfill these functions and ensure continuity between the roof and wall. As shown, the membrane flashings provide a barrier to moisture and airflow while the insulation keeps the membrane above the dew point to prevent vapor traps, which can be detrimental to both the roof and wall. This configuration also allows proper construction and coordination of the various trades as well as reduces the need for maintenance while increasing flashing life expectancy.

An explanation of the various protected membrane roof system configurations and air barrier requirements is as follows:

Fully Ballasted Insulation

Although the construction of most protected membrane roofs today typically specifies the insulation to be loose-laid, when these systems were first introduced, uplift forces were mitigated by positive attachment of the roof components to the structure and by the weight obtained by positive ballasting of the insulation. Typically, these systems have a good history of performance in Canada in regards to their ability to resist air leakage.

Figure 4. Shows decay of wood blocking caused by moisture transported via air leakage.

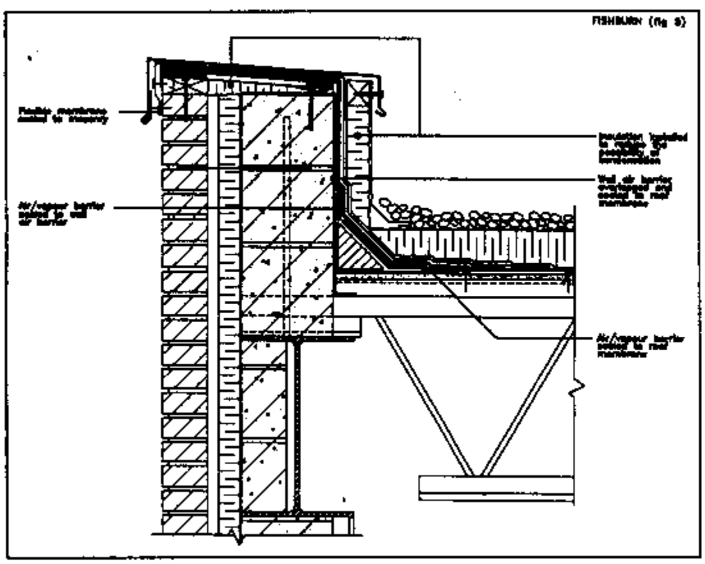

Figure 5. Airtight parapet junction (protected membrane roof).

Loose-Laid Insulation

Current design trends typically specify the insulation to be loose-laid and covered with a water-permeable fabric. With this approach, the weight of the aggregate or pavers that are typically used as ballast can be reduced to 49 kg/m^2 (10 lbm/ft^2). In this design, greater reliance is placed on the performance of the air/vapor barrier to resist the uplift forces.

The testing of air barrier systems is a relatively recent development. The impact of wind on loose-laid protected membrane roofs was studied and reported on by R.L. Wardlaw and R.J. Kind for the National Research Council (NRC), Bulletin 0015544 Design of Roof Types Against Gravel Blow Off.[7] Their study reported that loose-laid insulation remained in place because the suction applied to the insulation was much lower than that applied to the membrane because of rapid pressure equalization between the top and bottom surfaces of the insulation board. This accounts for the fact that 48.9 kg/m^2 (10 lbm/ft^2) of ballast is able to stay in place even when wind uplift pressures on the structure can be much higher. As demonstrated in wind tunnel tests, the slight suction acting on the insulation board is more than offset by the weight of the ballast. The ability of a loose-laid protected membrane and insulation ballasted with 49 kg/m^2 (10 lbm/ft^2) principally owes its wind uplift resistance to the airtightness of the roof deck substrate.[8]

Lightweight Latex Modified Concrete Topped Insulation

Preventing air leakage at the underside of the roof membrane, together with pressure equalization from the bottom side to the top side of the insulation largely accounts for the use of lightweight, latex-modified, concrete-topped insulation boards that weigh approximately 22 kg/m^2 (4.5 lbm/ft^2) to resist uplift forces. The insulation boards are often secured to the metal roof flashing at termination points and at the edge and corners with securement bars and/or pavers to provide additional protection against increased wind loads and scouring at these locations.[9]

In a roof assembly where the membrane is loose-laid, if the deck substrate is not designed to fulfill the function of an air barrier and air is allowed to infiltrate under the membrane, billowing of the membrane could dislodge the concrete topped insulation.

CONVENTIONAL ROOF SYSTEM

Conventional roof systems can be further defined based on the type of membrane employed and how the system is secured. These include:

- bituminous built-up roofing (BUR)
- fully or partially adhered single-ply or modified bitumen roofing
- loose-laid and ballasted single-ply roofing
- mechanically fastened single-ply roofing
- air-pressure equalized system

An explanation of the various conventional roof systems and their air barrier considerations is as follows:

Bituminous Built-Up Roofing (BUR)

On solid decks, such as cast-in-place or precast concrete, the installation of a solidly bonded bitumen-type vapor retarder

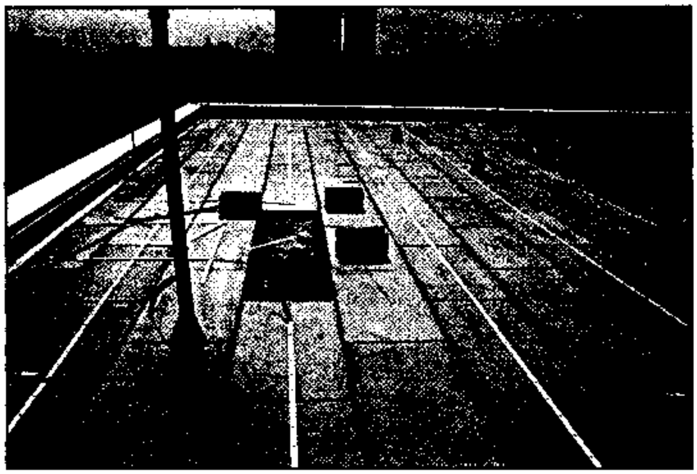

Figure 6. Shows lightweight, latex-modified, concrete-topped insulation damaged because of the lack of an air barrier in a loose-laid membrane system roof.

acts in unison with the deck to provide the air/vapor barrier. When the vapor retarder on a steel deck is loose-laid or partially adhered and the insulation mechanically fixed to the deck, the sandwiching of the vapor retarder between the deck and insulation provides a composite section to act as an airtight barrier.

The integrity and performance of the air barrier relies on each of the individual components acting in harmony with one another. The various components can be individually adhered, thereby providing several levels for reducing air leakage into or through the system. The type of adhesive, rate of application, and method of application are important considerations to ensure that the components remain solidly in place for the life of the roof system.

Although adhesives have typically been used in the past to adhere the vapor retarder and insulation in place, today, mechanical fasteners are more frequently employed and required by Factory Mutual for securing insulation to steel roof decks.

The amount of air leakage resulting from fasteners penetrating the vapor retarder has not been researched. The use of fasteners is acceptable and conforms to the NBC, providing that the infiltration of any moisture resulting from air leakage from the interior can be accommodated and without degrading the system.

Air leakage through fastener locations that penetrate the air/vapor barrier may be of concern partially in buildings with high humidity levels. To avoid penetration of the air/vapor barrier over a steel deck, a layer of cement board or a minimum layer of insulation could be installed and mechanically fixed to the deck. This would act as a base to solidly bond a membrane, such as two plies of No. 15 felt, with hot bitumen. The deck, cement board or insulation substrate, and membrane would then form a composite air barrier. When insulation is used, care must be exercised in the roof design to ensure that the dew point occurs above the air/vapor barrier.

As a matter of interest, both properly adhered and mechanically fixed bituminous built-up roofs can resist wind uplift forces exceeding 4.31 kPa (90 psf). Total pressure loads on the building can be calculated using a number of sources, including both national and provincial building codes.

Fully or Partially Adhered Single-Ply or Modified Bitumen Roofing

The subsurface construction of roofs designed and constructed for a modified bitumen membrane are similar to those employed for bituminous built-up roofs.

These systems do not usually employ gravel surfacing, are light in weight and, therefore, must bear the full impact of any wind uplift forces unless an air barrier has been employed. In addition to failure of flashings at the roof perimeter, wind-related failures in this type of system often relate to the loss of interlaminer adhesion between roof components and cohesive failure within the insulation. Prolonged exposure of the insulation to moisture, thermal cycling, and/or air leakage beneath the membrane have been shown to be contributing factors.

Any interlaminer separation between components will expose the roof membrane to differential stresses that could result in blow-off. Tests performed by Factory Mutual indicate that a properly designed and installed fully adhered membrane can easily exceed Factory Mutual I-90 requirements.[10]

The lack of providing a proper air barrier and the resultant problems that can occur if a proper air barrier is not achieved are similar to that of built-up roofs employing a sandwich-type construction.

The requirements for the installation of a vapor retarder are typically based on design and cost factors. Not considering the contribution of the deck to mitigate uplift loads, when the vapor barrier (if employed) insulation and membrane are totally loose-laid, the system acts as an air barrier with uplift forces being resisted principally by the weight of the ballast.

Loose-Laid and Ballasted Single-Ply Roofing

Loose-laid and ballasted single-ply roof systems are typically constructed with all components loose-laid.

Given a strict interpretation of the NBC and good design practices, it appears these loose-laid systems could benefit from the installation of an air barrier at the deck level.

It should not be assumed that the weight of the ballast typically specified at 48.8 kg/m² (10 lbm/ft²) will be sufficient to

Figure 7. Photo shows a blow-off of a modified bitumen roof. An investigation of the problem showed that air infiltration through the deck and lack of adequate securement at the roof perimeter were contributing factors.

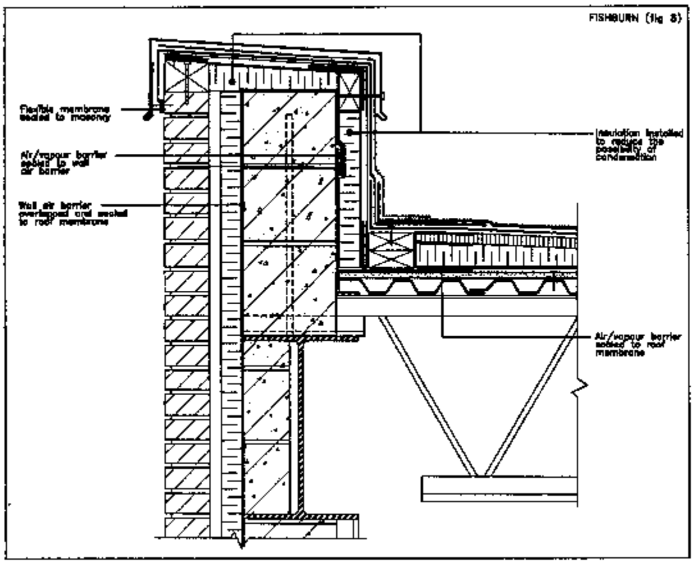

Figure 8. *Shows detail of how an airtight eave junction can be achieved (conventional modified bitumen roof).*

hold the roof membrane in place. Deck airtightness must be viewed as an important factor. The ballast will, of course, play a role depending upon its weight.

Unfortunately, not all insulations are dimensionally stable and may actually shrink while in service, thereby allowing joints of the insulation to open up and create pathways for potential condensation if air is cooled to its dew point. These pathways also allow air leakage. Air leakage at the joints of the insulation caused by positive interior pressure and negative exterior pressure caused by the wind can lead to billowing action of the membrane and displacement of the ballast. Under the influence of strong winds, the ballast will roll back into piles until sufficient weight around the area is obtained and resists further movement. If billowing of the membrane occurs on totally loose-laid systems, this action can also result in displacement of the insulation, which often piles up under the membrane.

Billowing action can result in rupturing of seams in the membrane and projectiles (ballast) being tossed over the sides of the building, thereby affecting the safety of pedestrians or vehicular traffic. For these reasons, it is recommended that considerable attention be paid to achieving airtightness at the deck level by the proper design and construction of an air barrier.

On a metal deck, the installation of a vapor retarder sandwiched between the deck and insulation may provide a suitable solution providing the insulation is mechanically fixed to withstand uplift forces.

As with all types of roof systems, condensation that results from air leakage in colder regions can be destructive and affect roof durability. This can result in the corrosion of steel deck and fasteners, wet insulation and dry rot and can contribute to the debonding of membrane field seams.

Mechanically Fastened Single-Ply Roofing

A mechanically fastened single-ply roof generally refers to assemblies where the membrane is attached to the deck using bar or spot fasteners.

Static wind load pressure testing is commonly used to determine the adequacy of mechanical fastening systems for single-ply membranes. In static pressure tests, the forces resisted by the membrane are transferred to the deck by way of the mechanical fasteners.

Research is currently being completed in Canada on the *dynamic* wind load testing of mechanically fixed single-ply roof systems. Although the work has not been finalized, early results indicate the performance of the fasteners is significantly affected when compared to static testing (due to bil-

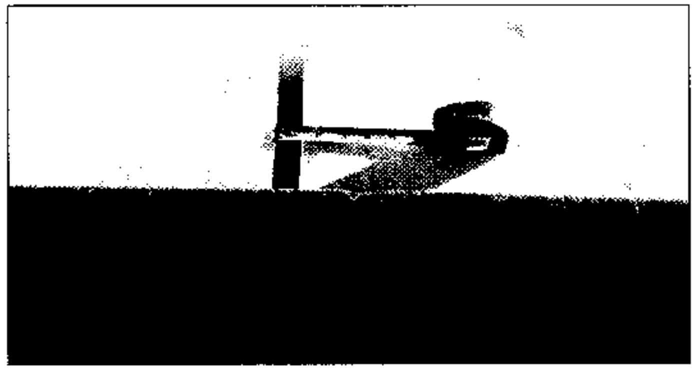

Figure 9. *Photo shows open joints of insulation under the membrane of a gravel ballasted roof. Open joints between the insulation boards provide a direct path for moisture ingression under the membrane.*

Figure 10. *Photo shows billowing action of membrane on an aggregate-ballasted EPDM roof.*

Figure 11. *Photo shows a polyester separation sheet frozen due to the accumulation of moisture from below on a gravel-ballasted roof assembly installed over a swimming pool. An investigation showed that air leakage resulted in dislodging the loose-laid vapor retarder, insulation and membrane.*

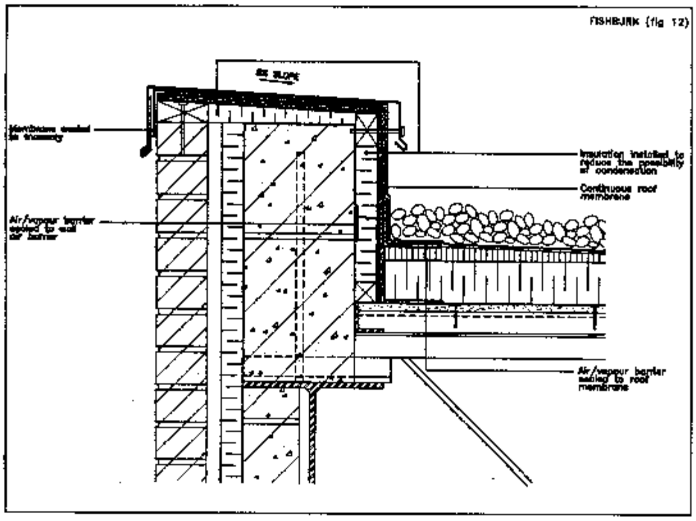

Figure 12. Detail shows example of how to achieve an airtight seal at a roof-wall junction using a gravel-ballasted EPDM membrane.

lowing or oscillating action of the membrane).

Although dynamic testing of mechanically fastened systems will increase the ability to predict field performance, empirical data on the role of the air barrier to substantially reduce the forces to which the membrane and its fastener system is subjected is minimal or nonexistent.

With current design practices, it is assumed that the full force of wind uplift pressures will be borne by the membrane, which must have adequate strength to prevent rupture. The type, size, location, and number of fasteners, including the type of fastening plates, are engineered to distribute and resist uplift forces.

This suggests that the membranes in these systems are expected to assume the role of the air barrier, the concept of which has been fostered via technical debates on membrane types and reinforcement, bar fasteners vs. spot fasteners, pullout strengths of fasteners, fastener failures and backout characteristics, seam strength and failure modes, and similar issues.

The installation of an air barrier at the deck level would substantially reduce the load on the membrane and fasteners and may render these discussions academic because of the fact that a properly designed and installed air barrier should resist most of the uplift forces and the membrane should be largely held in place by suction cup effect. The billowing action of the membrane over a properly designed and constructed air barrier at the deck level should be minimal. Unfortunately, under current construction practices, most mechanically fastened roof systems are not designed or installed in accordence with proper air barriers details. As a result, air leakage under the membrane typically takes place.

Air Pressure Equalized System

Unlike mechanically fastened systems, which rely primarily on fasteners to keep the membrane in place, this type of system relies on the airtightness of the deck or substrate keep the membrane in place. In this instance, the airtight substrate acts as the air barrier, and one-way pressure relief valves facilitate the escape of air entering the system, and uplift loads are thereby transferred to the substrate. Within the exception of anchoring the membrane at the roof perimeter and at roof openings, the roof membrane on these systems is loose-laid.

Air pressure equalization systems demonstrate that if a proper air barrier is installed on a mechanically fastened roof system, the load on the fasteners will be significantly reduced, and many of the wind related problems currently associated with single-ply systems would be eliminated.

Although the installation of a properly designed and installed air barrier could benefit all types of roof membrane systems, improvement in the performance of mechanically fastened systems could be significant.

When a mechanically fastened roof is installed over an existing roof, the old roof will act as an air barrier and, therefore, may be subject to substantial wind uplift forces. The old roof should be tested to ensure that it can withstand these forces. In addition, tests must be conducted to ensure that the existing roof is dry. Trapped moisture and wet insulation cannot only impact upon membrane performance but can also contribute to deck and fastener corrosion.

Because of the nature of the Canadian climate, billowing of the membrane, particularly with unreinforced EPDM, may result in water collecting at fixing points. This can result in damage of the fastening plates caused by freeze/thaw action as shown in Figure 17. Although it is generally accepted that a roof should be sloped a minimum of 2 percent to afford proper roof drainage, membrane billowing due to uncontrolled air leakage can result in water being trapped on the roof even when recommended slopes are achieved (see Figure 18).

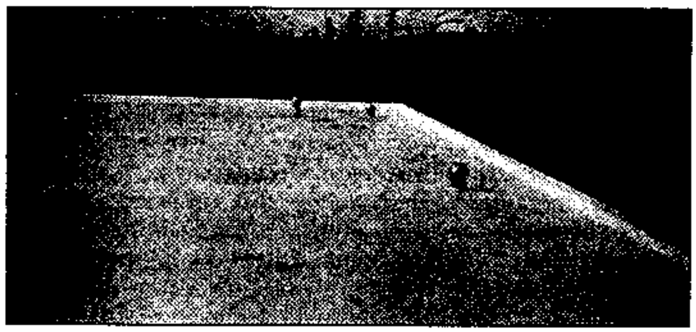

Figure 13. Photo shows a roof being held in place by virtue of the airtight substrate over which it is installed and by one-way pressure relief valves.

Figure 14. Photo shows billowing action in a mechanically fastened EPDM roof membrane caused by air leakage under the membrane.

Figure 15. Photo taken on the same roof as shown in Figure 14 depicts dislodged membrane caused by failed seam that occurred during billowing of the membrane.

The use of air seals at points of termination appears more critical with mechanically fastened systems because billowing of the membrane acts as an air pump to draw air and moisture into the roof assembly from inside the building. Billowing of the membrane can result in dislodgement of flashings at locations such as soil pipes, as shown in Figure 19. Figure 20 shows a detail of an air seal that could have helped prevent this occurrence.

The installation of an air barrier at the deck level on a mechanically fastened system could be provided by the installation of a bitumen, modified bitumen, or self-adhesive modified bitumen membrane installed over a concrete or wood deck.

Most mechanically fastened roof systems employed today do not incorporate separate air barriers installed at the deck level. Typically, most designs in Canada employ a heavy polyethylene vapor retarder sandwiched between the deck and the insulation to act as an air barrier. Overlaps and points of termination are typically sealed with caulking and butyl tape. Based on the author's field studies, this sandwich approach has not been adequate to prevent air from gaining access to the underside of the membrane. This is due to the fact that the self-tapping fasteners typically used to secure the insulation and membrane cuts a hole in the vapor retarder as the fastener engages the deck.

Experience has shown that insulation with a relatively low

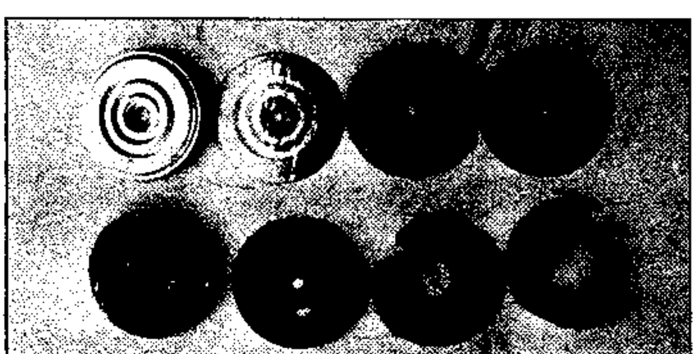

Figure 16. Photo shows corroded fastener plates removed from the roof shown in Figure 14. The roof was less than three years old and the insulation was found to be dry. Moisture carried by air leakage condensing under the membrane is suspected to be a contributing factor.

Figure 17. Damage of fastening plates due to freeze/thaw action.

Figure 18. Membrane billowing due to uncontrolled air leakage.

Figure 19. Dislodgement of flashings at soil pipes.

compression strength can, with the passage of time, adjust to the pressure under the fastening plate, thereby reducing the compression seal formed between the deck and underside of the insulation. Considering this phenomena, differential movement of the insulation and vapor retarder will occur because of wind loads, thus allowing air leakage into the system. The amount of fasteners penetrating the vapor retarder is significant because fasteners are used to secure not only the insulation but also the membrane. A similar phenomena can also occur if the insulation shrinks in service.

The positive and negative wind force pressures exerted on

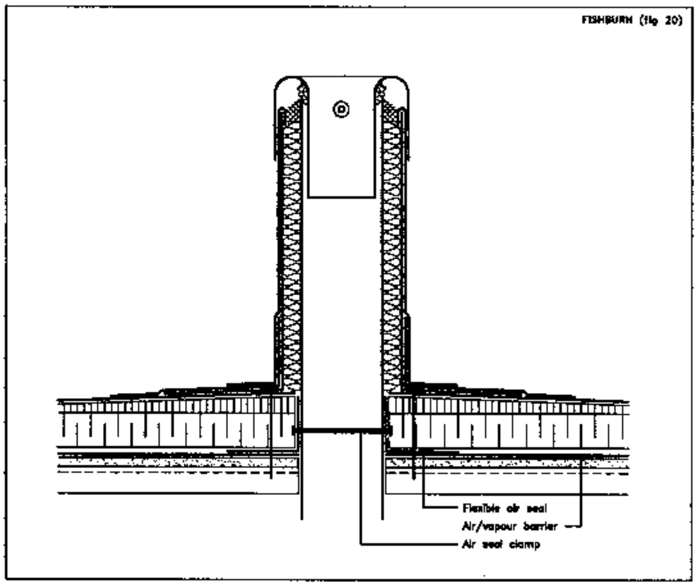

Figure 20. Air seal detail to prevent dislodgement.

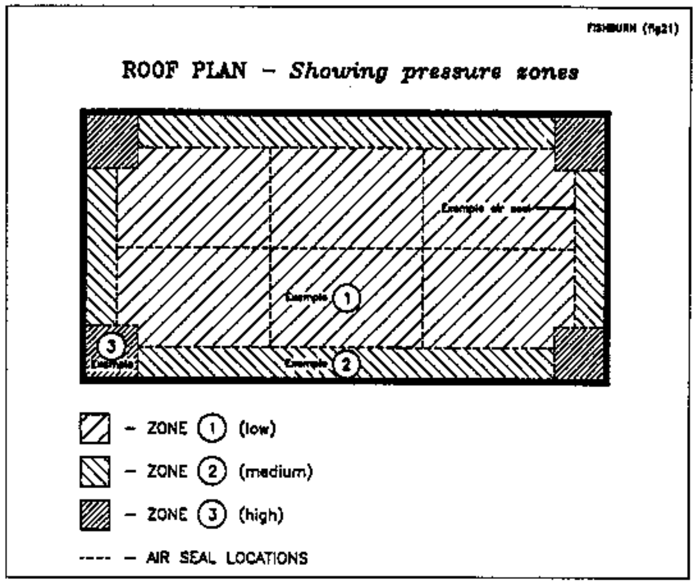

Figure 21. Roof plan shows examples of how roofs can be divided into pressure zones.

the roof assembly are seldom uniform. An increase in pressure at the corners or edges of the building may draw air from within the roof assembly, travel laterally under the membrane to the high pressure zone to allow billowing of the roof membrane under windy conditions.

To minimize the problem, in addition to providing an air barrier and positive air seals at the roof perimeter and roof openings, air seals (closures) should be installed within the roof, particularly at critical areas of high wind loading, to subdivide the roof into sections or zones similar to water cut-off joints.

In order to provide greater protection against wind damage at the roof perimeter, current design practices include reducing the spacing of bar or spot fasteners at zones of high pressure. Subdividing the roof into pressure zones will restrict the movement of air under the membrane. These dividers have a secondary benefit of also preventing the migration of moisture within the roof assembly should the membrane become damaged and water enter the system. These air seals (closures) should be compatible and capable of providing an airtight diaphragm between the air/vapor barrier or air barrier and the membrane. In addition, the air seal (closure) must be able to withstand the full impact of the forces to which they may be exposed.

A properly designed and constructed air barrier will eliminate most of the uplift forces acting on the membrane . If no air can enter beneath the membrane as a result of a properly constructed air barrier or travel laterally, then the forces acting upon the fasteners, seams, and membrane will be substantially reduced. Minor fluttering of the membrane sheeting can be expected because of wind flow over the membrane.

This paper has focused on the role of the air barrier and adverse effects on some roof assemblies if a proper air barrier has not been provided. The installation of a properly designed and constructed air barrier at the deck level will do much to improve roof system durability while increasing design life expectancy.

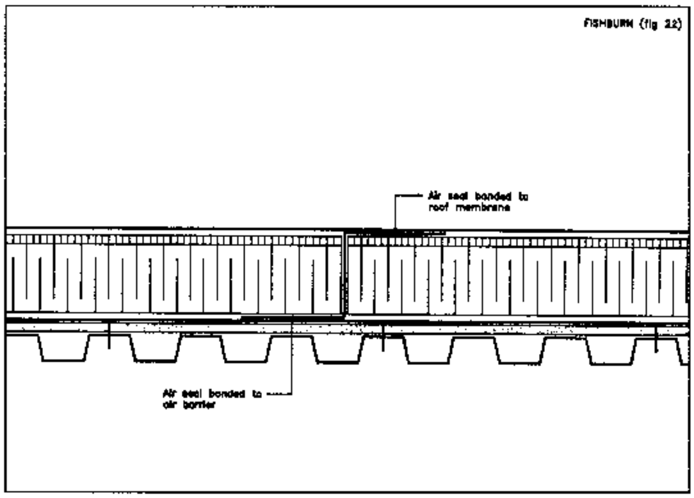

Figure 22. Section detail shows proposed air seal (closures) within the roof.

REFERENCES

1. Handegord G.O. Moisture Considerations in Roof Design, CBD73, National Research Council, January 1966.
2. National Building Code, Part 5: Wind, Water & Vapor Protection, Section 5.3: Control of Air Leakage, Subsection 4.3.1, National Research Council, 1985.
3. National Building Code, Part 5: Wind, Water & Vapor Protection, Section 5.3: Control of Air Leakage, Subsection 4.3.1, National Research Council, 1990.
4. National Building Code, Part 5: Wind, Water & Vapor Protection, Section 5.3: Control of Air Leakage, Subsection 4.3.1, National Research Council, 1995.
5. Quirouette R. L. "The Air Barrier Defined, Building Science Insight, 1986.
6. Quirouette, R. L. The Difference Between A Vapor Barrier and Air Barrier, Building Practice Note 54, National Research Council, 1985.
7. Kind R. J. and R. L. Wardlaw. Design of Rooftops Against

Figure 23. Photo shows a dislodged membrane on a mechanically fastened roof assembly that resulted from failure to provide an airtight perimeter detail.

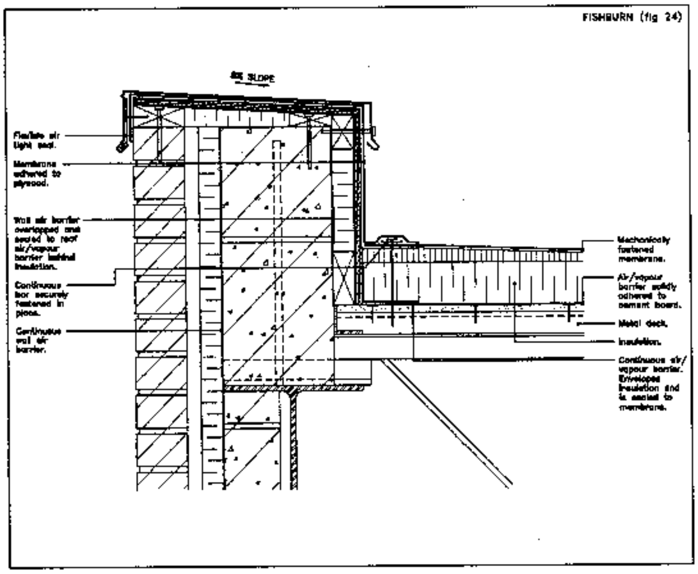

Figure 24. This section detail provides one approach that would eliminate this problem.

Gravel Blow-Off, NRC No. 15544, National Research Council, 1976.

8. Phalen, Thomas E. Jr. Stone Ballast Design Criteria on Loose-Laid Single-Ply Ballasted Roofs for Wind Speed, Size and Weight, Lincoln College Department of Mechanical Engineering, Northeastern University, Boston, Massachusetts, 1984.
9. Dow Chemical Canada, Roofmate CT Literature, No. 2474005A, 1994.
10. Factory Mutual System. Loss Prevention Data for Roofing Contractors, 1996.