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DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF AIR BARRIER SYSTEMS

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INTRODUCTION

Historically, the construction industry has not recognized that control of air flow is a major design requirement for building enclosures. Recently, after numerous failures, the need for this design requirement is being accepted by many who are involved with building design and construction.

It is now clear that unintentional air leakage is a major contributing factor affecting the in-service performance of building enclosures (walls, windows and roofs). It has been linked to the cracking and spalling of masonry, interstitial condensation, rain penetration, high energy costs, and poor control over the indoor environment. Nowhere is the need for improved airtightness more evident than in highrise construction where interstitial condensation and rain penetration have resulted in the premature aging or failure of exterior walls and cladding.

Failed attempts to prevent or effectively minimize air leakage through the use of vapor barriers, especially in highrise construction, have caused the introduction of "air barrier" materials and innovative techniques to improve airtightness of buildings. Suggested guidelines for the design, construction and performance evaluations for such materials and techniques are discussed under the following headings:

- Understanding Air Leakage
- Definition of Air Barrier System
- Requirements of Air Barrier Systems
  - continuity
  - structural integrity
  - air permeability
  - durability

- Position of Air Barriers
- New Airtightening Materials and Techniques
  - systems using flexible membranes
  - systems using rigid sheets of materials

UNDERSTANDING AIR LEAKAGE

Air leakage can be defined as the unintentional exfiltration or infiltration of air through the building enclosure. There are two conditions which must be present for air leakage to occur:

1. A hole or crack must be present in the building envelope.
2. A difference in air pressure must exist across the hole or crack.

Air Leakage Paths. Holes or openings through the envelope take many forms. They may appear as poorly sealed joints, or as cracks in mortar joints between masonry units, or around the perimeter of infill panels. These openings usually develop after construction due to differential thermal and/or moisture expansion and contraction of building elements, and by the elastic or creep shortening of building structures and the deflection of floor slabs. Some openings follow a direct path from inside to outside, such as through the flutes of a roof steel deck; others may appear on the inside surface finish, for example, behind a convector cabinet, above a suspended ceiling or various cavities.

Air leakage will also occur through porous materials, for example concrete block, high density glass fibre, open cell polystyrene and fiberboard.

In residential, wood frame construction, air leakage through the ceiling and outside walls may be greater than through holes around windows and doors. The main leakage paths occur through cracks between the gypsum boards and wood plates, and up through interior partitions into the attic space.

Air Pressure Differential. A difference in air pressure across the building envelope occurs either from wind, stack action, fan pressurization or any combination of these.

Wind. Buildings usually experience outward suction pressures on the leeward side, sides parallel to wind flow and over the roof area, and inward positive pressures on the windward side. As the wind changes direction the same opening may experience infiltration one moment and exfiltration the next. Depending on the direction and speed of the wind and on the shape and height of the building, relatively large suction pressures may be experienced at parapets, corners and on the facades parallel to the wind direction.

Although wind gusts can produce relatively high pressure differences across the building envelope, they usually are not sustained, lasting in the order of several seconds or less.

Stack Action. Stack action is a phenomenon caused by the difference in temperature that exists between the air inside the building and the outdoor air. If the air in the building is warmer than outside it will be lighter than the outside air. This effect causes the air within the building to rise to the top and exfiltrate through openings at the roof level. Simultaneously a suction pressure will occur at the base of the building which tries to cause air to infiltrate at the lower level. Stack action is more significant in cold climates and tall buildings.

Fan Pressurization. Most buildings are equipped with fans. Fans are called upon to bring fresh air in or to exhaust stale air from the building. If the supply and the exhaust rates are the same, they will not create any pressure difference between the inside and outside of the building. However, if the supply air is greater than the exhaust air, the building becomes pressurized. This in turn will force air to exfiltrate through any openings in the building envelope. On the other hand, if the exhaust is greater than the supply, this will cause air to infiltrate through the building envelope.

THE AIR BARRIER SYSTEM

The function of the air barrier is to control infiltration or exfiltration of air through the building envelope. The only practical way to achieve this is by reducing the number and size of unintentional holes or cracks. Whatever material or system is used to stop air movement, it must be able to resist air pressure differentials caused by wind, stack action or fan pressurization.

Any material or system of materials can be used to airtighten the building envelope if the following requirements are met:

1. The material or system must be continuous.
2. The material or system must be structurally supported to withstand air pressure differentials.
3. The material or system must be resistant to air flow.
4. The material or system must be durable.

Many common building elements such as wood, concrete, glass and gypsum board are impermeable to air flow, are structurally supported and are durable. By making the joints between these components airtight, the requirement of continuity can be met and an air barrier system can be achieved. Therefore the air barrier should be considered as a system. A system in which materials are joined together to form components which are joined together to form assemblies which are joined together to form a continuous system.

Continuity. The entire building enclosure, foundation, lower slab, exterior walls, and roof, must incorporate the air barrier system. The concept of system continuity is best visualized at the design stage with a technique known as the "red pencil test".

Without lift the red pencil from the working drawings, a red line should be traced through all the components and joints of the building enclosure which comprise the air barrier system. For example, the line of airtightness may start at the floor slab-on-grade, continue through the interior cladding, through the window assemblies, and through the roof system.

At every location where different materials meet or various components intersect, design details should be separately developed illustrating the method by which continuity of the air barrier system is maintained.

Although the air barrier system can be identified on the drawings with a single red line, on site it consists of different materials and components of various thicknesses. This implies that additional coordination will be required on site between all trade involved in providing a continuous air barrier system.

Structural Integrity. An air barrier system must be designed to withstand relatively high wind loads of small duration, small but sustained undirectional loads, and small cyclic loads caused by wind fluctuations, for the entire life expectancy of the building. If the air barrier system does not withstand these design loads, then the system may rupture or detach from its support and cause the wall or roof assembly to experience permanent increased air leakage.

As a starting point, the authors suggest that the structural design of air barrier systems be based on wind load factors used for the design of cladding and curtain walls. The following laboratory tests are proposed for the structural evaluation of such systems and are currently being developed at the National Research Council of Canada and at Trow's head office laboratories.

A test assembly is built which includes typical details of the proposed air barrier system. The test assembly is placed in a specially design test chamber which can either be pressurized or depressurized and subject to dynamic loading. Another technique for evaluating air barrier systems, developed by Dr. John Timusk at the University of Toronto, uses two identical test specimens placed back to back. In this technique, a separate test chamber is not required.

The air leakage of the test assembly is measured at a specified pressure differential. The test assembly is then loaded to a pressure differential of 2.5 kPa for a duration of five seconds. This is repeated three times. If no significant increase in air leakage is observed, the specimen is then loaded to a pressure differential of 1 kPa for one hour and the air leakage measured. A third test is done with the assembly loaded to 150 Pa for a duration of 8 hours. All of the above tests are conducted under both positive and negative pressure differentials. Finally, the test assembly is subjected to 100,000 cycles of load ranging from positive 150 Pa to negative 150 Pa with a cycle length of 5 seconds.

Successful performance of the air barrier system is demonstrated by no significant increase in air leakage.

The latter tests are designed to simulate low pressure loads that occur on buildings which could lead to a gradual loss of airtightness due to creep and plastic deformation of the materials comprising the air barrier system.

Another issue which should be addressed is the stiffness requirements of air barrier systems. The authors believe that stiffness criteria may be necessary to ensure that pressure equalization is realized in designs incorporating the "rain screen principle". Although theory supports this view, testing is necessary to establish the exact relationship between pressure equalization, compartmentalization and stiffness of the air barrier system.

Air Permeability. Theoretically, it can be argued that the air barrier system should experience zero air leakage. However, it is not practical to expect that this can be achieved in the field without significant cost. On the other hand, it is not yet known what would be an allowable leakage rate that would minimize moisture related problems or be acceptable from a noise, dust or energy control point-of-view. Based on the authors' experience, it is suggested that the degree of airtightness be a function of the height of the building. An opening at the top of a 30-story high building could experience much greater air flows, due to increased wind and stack action, than an opening of the same size in a one-story building.

There is at least one standard test procedure available for measuring the air permeance of materials. A limited number of common construction materials have been tested and the results published (Bomberg). Such values relate to individual materials and cannot be extrapolated to the overall air barrier system. Because the joints in an air barrier system are usually the critical areas in terms of air leakage, the whole air barrier system must be tested and a rate of air leakage determined.

Some industry standards have already been set in terms of overall air leakage. In particular the curtain wall industry in the U.S. has adopted the AAMA guidelines which require that such systems must not experience an air leakage rate greater than 0.06 CFM per square foot at a pressure differential of 1.57 pounds per square foot, or 0.3 litres per second per square meter at a pressure differential of 75 Pa.

In Canada, curtain wall systems routinely meet an air leakage criteria that is half of the AAMA guidelines. Based on the authors' experiences with moisture related problems due to exfiltration and the severity of the Canadian climate, it is suggested that air leakage rate through the building envelope or the air barrier system be limited to .10 litres per second per square meter, regardless of the type of construction, at a positive and negative pressure differential of 75 Pa.

As more information becomes available from practice as well as experience in the field, the leakage rate criteria will be adjusted either up or down.

Durability. An air barrier system must be as durable as any of the substantial components which make up the building envelope. While it is difficult to determine which materials will perform and last a reasonable length of time within a wall or roof assembly, experience has shown that materials such as concrete, glass, steel and masonry can be durable; materials such as polyethelene film, certain types of insulation, mastics and sealants may not have the desired life under the conditions in which they are expected to perform.

POSITION OF AIR BARRIER SYSTEM

From a dust, noise and energy control point-of-view, the air barrier can be positioned anywhere within the building envelope, i.e., on the exterior or the interior of the wall or roof assembly or within the assembly itself. In many cases the type of construction will dictate the most cost effective place to position the air barrier.

However, if durability of the air barrier is considered, the preferred position of the air barrier is towards the inside of the insulation and the building enclosure, where it is protected from environmental extremes and radiation.

In some types of highrise construction, exposed shear walls of cast-in-place concrete are also used as part of the air barrier system. In colder climates, exposure to temperature extremes has resulted in the problem of continual maintenance of cracks which form in these walls.

Since most roofing systems also function as an air barrier, either by design or accident, the protected membrane roof system is a much preferred system. Because the membrane is positioned below the insulation, it follows that all principal requirements of air barrier systems are satisfied.

It is impervious to air flow, structurally supported and continuous. In addition, because it is at a more stable environment protected from degradation due to solar radiation, the optimum durability of the membrane in a well designed and constructed system is achieved.
For wall assemblies, an additional benefit can be gained by positioning the air barrier towards the inside of the building enclosure, i.e., interstitial water or condensation can be vented or drained from the wall cavity to the outside.

By definition, the air barrier can be considered an airtight skin. If it is located on the exterior of a wall assembly for example, drainage or ventilation openings could not be incorporated into the wall design to effect wall drying, as would be the case if it was located on the interior. All of the above arguments are applicable for air conditioned climates as well as heated climates.

APPLICATION TECHNIQUES AND NEW TECHNOLOGIES

The realization that plastic vapor barrier sheets are inadequate for use as air barriers has resulted in the introduction of new materials and techniques being promoted as air barrier systems. These may be categorized as follows:

- Systems using flexible membranes
- Systems using rigid sheets of materials

Systems Using Flexible Membranes.

Several types of air barrier systems employ flexible membranes of either rubberized materials or modified bitumens attached or adhered to structural components of the building envelope. Both of these materials are similar to nature to single-ply roofing or waterproofing products.

EPDM or synthetic rubber comes in sheets of various sizes and 3 to 6 mm thick. Its most common application in wall assemblies is to serve as an air seal at locations where two or more rigid airtight building components meet. In one particular use, a flexible piece of EPDM is fastened into the perimeter extrusion of a curtain wall assembly and mechanically attached to the adjacent concrete structure, creating an airtight seal.

Modified bitumen materials, on the other hand, are continuously adhered to a structural substrate. They can be adhered using either heating/melting techniques or stuck to the substrate using adhesives. Membranes requiring heat for application are known as thermofusible membranes. These membranes are reinforced with either glass scrims or polyester mats and typically come in 30 inch wide rolls. During the application process the thermofusible membrane is rolled onto the substrate, such as brick veneer or concrete block infill panels, and heated with a torch until the bitumen becomes tacky and sticks to the substrate. The substrate is usually entirely covered with the membrane. Penetrations through the membranes such as brick ties or other structural connections are easily sealed with the application of additional heat.

Non-reinforced membranes, with one side of the membrane precovered with adhesive, are also available in 30 inch wide rolls. These membranes do not require the application of heat; instead the release paper is peeled off and the membrane pushed tightly to the substrate.

Another type of flexible membrane system uses large rolls of spun bonded olefin material which is wrapped around the exterior of the building envelope. Although the authors are aware of its use only in lowrise residential construction, it would have to be structurally supported on both sides to meet the air barrier requirements previously listed.

Systems Using Rigid Sheets of Materials.

Two systems commonly being adopted for highrise construction include a system which uses sheet steel and a system which uses the interior gypsum board.

Sheet steel in the form of 22 gauge galvanized sheets, is fastened to the building structure, usually next to the exterior cladding, with mechanical fasteners. The sheets of steel are made airtight at the joints with sealants normally used in the construction industry. Expansion and contraction joints may also be incorporated into the design.

The second approach uses the interior gypsum board sealed to the structural components of the building to create a continuous air barrier. Drywall to drywall joints are sealed using normal tape and compound filler. Joints between drywall and other building components are sealed with either gaskets or flexible sealants.

In all of the approaches above, rigid airtight materials commonly found in the building envelope are sealed together in some airtight fashion. Although many of these materials individually exhibit good air permeability and structural properties, little or no test data is available evaluating the overall performance of these air barrier systems.

CONCLUSIONS

For an air barrier system to perform as intended it must be continuous, structurally supported, have zero defects in the materials chosen to compose the assembly, or have a low air permeability, and be durable. If any one of these conditions is not met by design then it can be said that the air barrier system is not likely to perform for the length of time desired.

Once the air barrier system has been designed and incorporated into the working drawings, a combination of laboratory and field tests designed to evaluate the structural and air leakage performance of the system, combined with on site quality control, is the best way to ensure that the air barrier system will perform as intended.

Traditional methods of wall design and building envelope construction must now take second place to the newer innovative techniques that will adopt the technology of an air barrier for the building envelope.