THE AIR BARRIER

An article written for the
Wikipedia Encyclopedia
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September 2015

INTRODUCTION

Following the energy crisis of 1973, in the decade that followed owners of buildings began to insulate their buildings to higher levels of thermal resistance (increased "R" value) with more thermal insulation. Not long into the process of re-insulating existing buildings, a diversity of building envelope problems began to appear to include; condensation in walls, icicles on claddings, spalling of masonry, corrosion of metal fasteners and brick ties, rotting of wood sheathing and sidings, water leaks from roofs in spring only and other moisture related problems. It was also reported that even though insulation had been installed or retrofitted, that energy cost remained high with little or no savings for building owners. The cause was eventually isolated to excessive air leakage through the building envelope (roof, walls, windows, foundation walls and below grade floors).

Initially, attempts were made to reduce air leakage through the building envelope by improving the design and installation of the vapour barrier as required by the 1980 National Building Code of Canada (NBCC) and previous versions. In a few years small improvements were noted in the reduction of moisture damage due to condensation but air leakage continued to occur to the detriment of the building envelope as it aged. For a long time the cause of the continuing air leakage problem was attributed to faulty or poor workmanship with the vapour barrier. The industry of professionals, designers, builders and inspectors, and various institutions continued to push for a better quality of vapour barrier installation and more resistant materials.

In 1980, a research project was undertaken by the Institute for Research in Construction (IRC) of the National Research Council of Canada (NRCC) to determine the exact cause or causes of the above noted dilemma. This project was the keystone of the birth and evolution of the new science and technology of the Air Barrier concept.

This article outlines the research findings of the IRC/NRCC related to the cause(s) of uncontrolled air leakage through the building envelope; introduces the new science and technology required by the construction industry to better control air leakage; introduces the structural air barrier concept and its performance requirements for designers and builders; adds appropriate new minimum requirements to the National Building Code of Canada with a mandatory required air barrier system. It also examines further research by IRC/NRCC, CMHC and private laboratories into testing of materials, construction assemblies and buildings in the field. There are now numerous associations, committees and manufacturers involved in the developing science and technology of the air barrier concept.

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AN IRC/NRCC RESEARCH PROJECT

At the invitation of PCL Construction Ltd, one of Canada's largest construction companies, with a head office in Edmonton Alberta, and a company investigator named Jean-Claude Perreault, IRC/NRCC sent a research officer, (the author), to examine the process of construction of large buildings in western Canada and in northern climates. PCL claimed that no matter how well they followed the plans and specifications for a building project they were often faced with building performance problems and specifically building envelopes that exhibited unacceptable air leakage with its attendant symptoms and moisture problems.

The researcher, a graduate architect, examined well over 30 medium to large buildings in various stages of construction and reviewed the plans and specifications for each. During a three month period, the researcher visited buildings in the cities of Edmonton and Calgary of the Canadian province of Alberta, the city on Vancouver in the Canadian province of British Columbia and the city of Yellowknife in the Canadian North West Territories. An examination of the design and construction of the vapour barriers for these buildings eventually led to an important discovery: the vapour barrier assemblies were failing to control air leakage (rupturing, tearing, unsticking) due to an air pressure difference caused by wind, stack effect and or fan pressurization. (1)

It was discovered that the science of building envelope design was incomplete with respect to air leakage control. It had not yet been realized that air leakage control was not a workmanship issue alone but rather a structural design issue related to the strength adequacy and durability of the intended barrier to limit or prevent air leakage through a building envelope. While it was known that a pressure is required to push air through an assembly, air pressure also exerts a force on the barrier intended to limit or prevent air leakage. If the barrier is relatively air tight then the air pressure may become a significant force on the barrier. This force in turn tears at the continuity of the barrier, rupturing or tearing at joints to allow an air leakage increase to alleviate the air pressure difference load on the barrier. This force is therefore a structural requirement for the barrier, a requirement that was absent from the science and technology of air leakage control up to about 1985.

THE DIFFERENCE BETWEEN THE VAPOUR BARRIER AND THE AIR BARRIER

In the years to follow, initial research into this discovery led to a series of demonstrations for the research community at first and then the professionals of the construction industry. A demonstration consisted of attaching a polyethylene film vapour barrier (VB) to a wood frame and then to a specially designed pressure box (figure 1). The sample vapour barrier was attached to the wood frame, with a lap joint in the middle, sealed with acoustical sealant, taped and stapled. The pressure box was equipped with a fan, a speed controller, an air flow meter and a pressure monitoring gage. A demonstration would consist of pressurising the box to simulate a wind pressure load on the construction assembly and the polyethylene film VB.

Initially, at low air pressure difference, the air leakage through the polyethylene VB was small to none. As the pressure of the box was increased, the polyethylene VB would billow outward between the studs. At about 100 Pa (0.40 in. H_2O) or about 5% of the design wind pressure load on a building, the VB joint would eventually tear apart. The rupture caused the air leakage to increase through the VB and the box air pressure pressure to decrease.

In construction there are numerous variations on the installation of a polyethylene VB. In some cases the polyethylene VB faces a void or cavity, in another case the film is supported on one side with insulation, in another case the poly is sandwiched between sheathing on one side and rigid insulation on the other. This is the reason air leakage control performed satisfactorily in some buildings and failed prematurely in others. If the VB film was supported on both sides it would perform satisfactorily and for a longer period of time. It is these demonstrations that led to the requirement for a distinct new building envelope science function, the structural air barrier or simply **the air barrier concept**. It was then decided that a distinction should be made between the VB and the air barrier (AB) system [(2)].

The Vapour Barrier

The original VB concept was developed in the 1930's [(3)] to prevent or limit the diffusion (a molecular process) of water vapour form migrating from a region of high humidity at ambient temperature to a location of low temperature where condensation would occur. In the 1920's, 30's, and 40's building were being insulated for increase comfort and better indoor temperature control. As a result of the added thermal insulation, condensation began to occur in walls and roofs of buildings. It often accumulated in exterior walls and roof cavities only to thaw out all at once in early spring. This thaw would manifest itself as wetness at the base of walls or under ceiling lamp fixtures to cause severe moisture damage indoor and in exterior walls. Cold surfaces generally occur on the outer parts of an exterior wall or roof in winter in the northern latitudes and on the inner side of walls and roofs in southern high humidity climate with air conditioned rooms.

Initially the VB was a construction paper infused with tar or asphalt, a water repellent, and placed on the warm side (the high vapour pressure side) of the insulation in building in northern latitudes. Eventually VB papers were replaced with the ubiquitous polyethylene film VB. It was installed as a 4 mil (thousandths of an inch) film, lapped, taped and caulked. The performance requirements for the VB are;

1. The VB material must be vapour impermeable,
2. The VB application must be continuous within the building envelope,
3. The vapour barrier must be applied on the high vapour pressure side.

A vapour barrier is not required to control air leakage through the building envelope. Other materials can also perform as the primary VB. These include most recent peel and stick membranes, various water vapour impermeable paints and vinyl wall papers to name a few. There are also unintentional VB materials such as precast panels, metal cladding, stuccos, vinyl siding and certain exterior construction papers to name a few. For more information see the Vapour barrier on Wikipedia.

The Air Barrier

The air barrier concept came onto its own in 1981. It was officially introduced in the 1985 National Building Code of Canada as a separate requirement from the vapour barrier requirements. The performance requirements for the air barrier system are;

1. The AB material must be air impermeable,
2. The AB system must be structurally supported to resist failure from wind, stack and or fan pressurization pressure differences,
3. The AB application must be continuous through the building envelope,
4. The AB must be as durable as the structure of the building or serviceable.

1. Air **Impermeability**

The air barrier system must be constructed of air impermeable materials. To control air leakage through a building envelope, a layer of materials must be sufficiently air tight. It need not be perfectly air tight but it must be less than a prescribed limit to control condensation, limit rain penetration, limit insect infestations, maintain fire protection measures, maintain noise control from outdoor sources, maintain temperature and relative humidity conditions and limit excess energy loss to name a few. A prescribed limit was defined in 1986 in a seminar workshop by the

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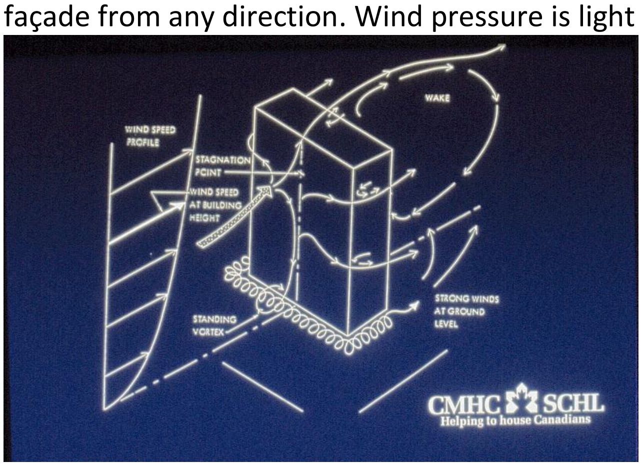
IRC/NRCC titled "An air Barrier for the Building Envelope". While not definitive for all applications, it was noted that the air permeability of the air barrier system be limited to 0.01 L.s.m2 (0.002 cfm/ft2) at 75 Pa (1.56 psf) pressure difference of air barrier surface. Because an air barrier system is composed of numerous types of materials, this air permeance limit is applied first to the individual materials. In the mid-90s, the Canada Mortgage and Housing Corporation of Canada undertook to develop a standard to determine the air permeance of materials and to publish a report on the air permeability of common construction materials used in air barrier construction. [18] The published data includes self-supporting materials such as gypsum board, plywood, concrete walls, precast panels, certain metal cladding types etc. Flexible materials such as membranes that are supported on both sides and air impermeable, includes polyethylene film, peel and stick membranes, thermos-fusible membranes, various construction papers to name a few.

2. Structural Design

The structural property of the air barrier is the 2nd requirement of the air barrier system. The air barrier system differs from the VB in that it must be designed to resist air pressure loads from wind, stack effect and fan pressurization. It must be designed and constructed to resist failure from the wind load pressure difference, stack effect and fan pressurization. Wind load pressure difference varies with the geographic location, exposure to wind, wind direction and the shape of the building. While wind pressure is variable with wind speed, stack effect and fan pressurization pressure differences are small in intensity but generally sustained for long periods of time. Stack effect and fan pressurization may cause an air barrier to fail eventually if it is assembled with tapes, caulking and or glues. The small but sustained pressure difference tugs at all joints and surface adhesives to peel the barrier from it substrate of to pull apart membrane joints.

a. Wind pressure (Fig. xx) is variable in its intensity and may impact on a building façade from any direction. Wind pressure is light when averaged over long periods but strong at times for hours. The NBCC defines design wind loading on an hourly basis for most locations in Canada and gust wind loading as a ratio of the hourly wind load. Because wind pressure can occur from any direction it can produce a positive pressure on a façade (pushing on the outdoor surface) while producing a simultaneous negative (pulling on the outdoor surface) pressure on other facades and roofs. Hourly design wind pressure is typically about 10 psf (xx.x kN) but can be much higher at select geographic locations. The NBCC Part V 1985 and later versions all require that the air barrier system must resist the air pressure loads caused by the wind.[4]



b. Stack effect is a thermal phenomenon (Fig. xx). Warm air surrounded by a mass of colder air will attempt to rise in the cold air. The term stack effect comes from the warm air rising in a chimney. The warmer the air the faster it rises. The warm air balloon is another example of this effect. Propane heating is used to warm the air in a balloon thereby increasing the air buoyancy of the balloon. As the temperature rises, the balloon eventually rises to carry the balloon, the basket and its occupants aloft. Buildings are similar to balloons. In winter when the outdoor air is cold and the indoor air is warm the indoor air rises in the building to push on the roof and the upper parts of the exterior walls. The pressure is not strong enough to lift the building but it can and does push indoor air through any through path opening to the outdoor.

While the pressure difference is weak by comparison to wind, it is sustained for long periods of time, sometimes months. This air leakage often causes condensation in roofs and exterior walls and is a major cause of high energy cost for heating. This sustained pressure difference can and does cause air barrier joints to fail, particularly when acoustical sealant is used to seal membranes at lap joints. It also causes peel and stick membranes to un-bond from a substrate eventually to fail its air barrier function. [5]

c. Fan pressurization is a source of air pressure difference on most building envelopes. New and many older buildings are now equipped with a ventilation system for the comfort of the occupancy and or the contents of the building. A ventilation system comprises one or more fans to supply fresh air into the building and to exhaust stale air out. When the ventilation air flowing into and out of the building is equal, the ventilation system is said to be balanced. However, engineering practice is to offset the flows in favour of a slight pressurization (Figure xx) or slight depressurization. This depends on the geographic location and on the type of occupancy.

In colder regions, buildings are slightly pressurized to offset infiltration of cold air at ground level. In hot climates buildings may be slightly depressurized to preserve the air conditioned air. Whether pressurized or depressurized, the ventilation system and therefore the fans cause a small but sustained pressure difference on the building envelope [17]. This sustained pressure difference has the same negative effect on membranes and joint materials as with stack effect.

3. Continuity

The continuity of the air barrier system is the 3rd fundamental requirement. The building envelope is composed of many layers of varying function and varying construction materials. In roofs, the air barrier may be a membrane made continuous throughout the roof surface and connecting to the air barrier layer of the exterior walls. The air barrier must also extend to the foundations and even the below grade floors. It must be connected throughout at all junctions and joints with other components of the building. Air tight flexible connections to windows and door frames are most important.

4. Durability

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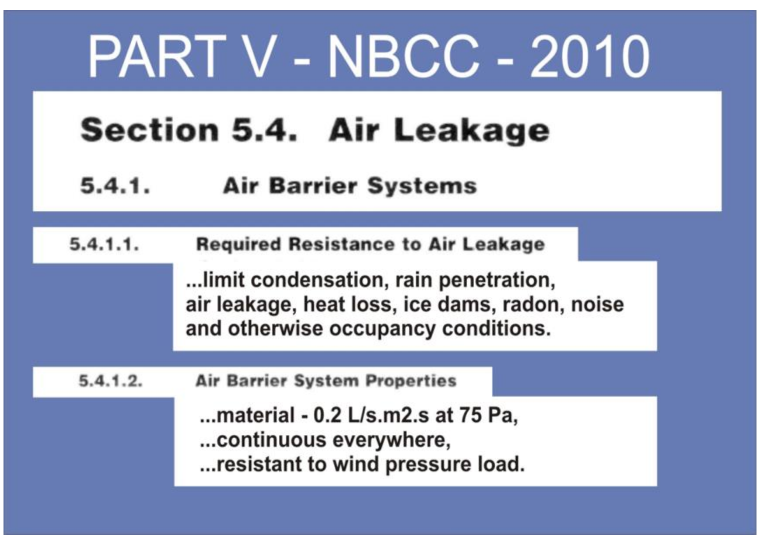
Durability is the fourth (4th)) requirement of the air barrier system. While durability is not a property of a material, the materials of the air barrier system must be selected for the environment in which they will perform. That is high wind locations require higher structural resistance. The materials must accommodate all temperature environments from the cold of the North to the hot and humid or dry climates. They must be resistant to coastal salty regions. In addition the indoor condition must also be considered from normal ambient office conditions to the toxic environment of industrial and even laboratory occupancies.

In general, it is expected that the air barrier system will perform it function for the life of the building or the life of the structure in particular.

A NEW BUILDING CODE REQUIREMENT.

The National Building Code of Canada (NBCC) Is for the most part a minimum standard building code developed at the National Research Council of Canada as a model code. The building code is organised into several sections titled as Parts. Notwithstanding the Administration and Occupancy Parts, there are two Parts that pertain directly to the air barrier concept. These are Part 5, The Heat Air and Moisture Section and Part 4 on the Structural Design Requirements for Buildings. Part 5 is developed on a consensus basis. Part 4 is developed on the science and technology basis of structural design. It is revised and upgraded periodically usually every 5 years. It is then adopted by the individual provinces of Canada as their provincial code as is or with minor modifications relating to regional differences in construction.

It was recognised by a research officer, Gordon Plewes, of the structural committee for the NBCC in the early 80's that an air barrier system is a structural system as much as the structure of any building. Through research and discussion in the early 80's, the committee on Part 5 saw the wisdom of introducing a separate and distinct requirement for the air barrier in Part 5 of the NBCC 1985 Edition in addition to the existing requirement for the vapour barrier. The introduction of the air barrier into the 1985 building code included the structural requirement for the 1st time. It has since then evolved into a performance requirement to include specific design requirements for air permeability, the structural criteria and the continuity of the air barrier system. The statements above are the most recent requirements of the air and vapour barriers of the 2010 NBCC.



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The application of these requirements are subject to interpretation.

APPLICATIONS

The air barrier is required by all building envelopes where the occupancy requires separation of the outdoor environment from the indoor environment. It is required to support control of the conditions within indoor environment and especially to conserve energy. Building types include residential, commercial, institutional and industrial buildings. The air barrier system need not be on the high vapour pressure side as the VB does unless the air barrier materials are not only air impermeable but also vapour impermeable. Air barrier design is in its early stages of development even though it has been required in Canada since 1985.

There are two types of air barrier systems;

a. the self-supporting type such as boards and panels rigid enough to transmit the wind pressure load to its connections without excessive deflection or deformation,

b. the membrane type which requires structural support on both sides of the membrane. For example a membrane air barrier system may be supported on one side with a plywood panel and on the other with a dense insulation system. In this type the air barrier system comprises three components.

Lastly, junctions and joints of the air barrier system layer must also be structurally adequate. Generally a junction occurs between two types of air barrier materials and a joint is between the air barrier material and a component such as at a window or door frame. The joint must be flexible to accommodate live loads, thermal and moisture movements as well as resist all air pressure loads.

A building envelope is generally composed of a roof, exterior walls, windows, doors, foundation and a below grade floor. These areas of the building envelope are characterized as assemblies. Each assembly contains many layers of materials but each layer generally provides a particular function within the assembly. The functions include:

a- control of air leakage,
b. control of rain, snow and melt water penetration,
c. control heat loss or gain,
d. control of water vapour diffusion and condensation,
e. control of smoke and fire propagation,
f. control of noise penetration,
g. be strong and durable. [xx]

The control of air leakage is provided by the air barrier. The air barrier is the single most important function of the building envelope as all other functions depend on it to perform their function. For example, no matter the amount of insulation in an assembly, heat loss (energy loss) becomes uncontrolled if the indoor air leaks out liberally to be replaced by outdoor cold air. If the air barrier is omitted from the building envelope, air entrained moisture (from wind driven rain) will penetrate to the indoor, excessive condensation will occur in assemblies no matter the vapour barrier condition, smoke control and noise control fail to perform as intended. It is imperative that any new building envelope include an air barrier system as described above.

Buildings and the building envelope in particular are first designed by an architect or a building designer. The building envelope is then constructed by a builder or contractor. The performance of the air barrier system depends of the design attributes that include the specified materials, the structural requirements, the design details for continuity and the expected durability and or serviceability of the air barrier system. The air barrier system is constructed by the builder or contractor as part of an assembly. It is important that the sequence of construction supports compliance of the assembly with the design documents.

Materials selected for the air barrier system must be air impermeable but are often vapour impermeable as well. ……………………………………….

TESTING AIR BARRIER MATERIALS AND SYSTEMS

The air barrier system is not required to be on the high vapour pressure side of an exterior wall or roof unless the material selected is also vapour impermeable.

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