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Structural
Requirements
For Air Barriers

REPORT

Structural Requirements For Air Barriers

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

DISCLAIMER

This study was conducted by the Morrison Hershfield Limited for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the consultant and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

EXECUTIVE SUMMARY

The National Building Code of Canada requires that buildings are provided with an *effective* barrier to air exfiltration and air infiltration. The component(s) within a building envelope which provide "airtightness" for a building is called the "air barrier".

The National Building Code requires that an effective barrier must be provided to air exfiltration and air infiltration. The NBC also requires that "air barriers" be designed. Canada Mortgage and Housing Corporation has retained Morrison Hershfield Limited to undertake a study regarding the requirements for structural design of air barriers.

Designers are generally unaware that an air barrier may be subjected to significant air pressure due to wind effects on a building and that an air barrier will only be effective as long as it is able to resist these loads. Designers are also generally unaware that there are lesser magnitude but longer acting air pressures such as those due to stack effect which must be resisted by air barriers. Low magnitude constant loads can cause failure of some building materials due to creep. There are other low magnitude but constantly fluctuating loads such as daily wind gusting which can cause fatigue failure of some building materials.

Air barriers are structures and are subjected to air pressures from mechanical pressurization, stack effect and wind. When an air barrier within a wall construction fails due to being structurally overloaded it ceases to perform as an "air barrier". This can occur without detection with the likely consequences of accelerated rates of building envelope deterioration due to corrosion, freeze-thaw damage, efflorescence, etc. For an air barrier to be *effective* it must be capable of supporting the air pressure loads which will act on it during it's life.

The development of structural design requirements for air barriers will enable designers to better ensure that air barriers function for their intended life.

The following chart indicates the types of loads which must be considered in structural design of air barriers.

TYPE OF STRUCTURAL FAILURE			
Type of Loads Contributing to Structural Failure	**Static Strength**	**Fatigue Strength**	**Creep Strength**
Extreme Wind	•		
Commonly Occurring Winds		•	
Stack Effect	•		•
Mechanical Pressurization	•		•
Restraint to Thermal Expansion Contraction	•	•	•

The basic objective of structural design is to assure that there is an acceptably low probability that strengths of a structure (static, fatigue, creep) will be exceeded by the loads acting on the structure. A structural designer compares an upper bound value of loading with a lower bound value of structural strength to determine structural adequacy.

The following chart indicates the process of structural design required in order to ensure that an air barrier will be able to resist loads imposed on during its functioning life.

The following report provides guidance on the structural design process for air barrier systems.

The report presents a summary of what is known regarding the magnitude and frequency of air pressure loading on air barriers arising from wind, stack effect and mechanical pressurization. Building code provisions for these types of loads are reviewed and their applicability to air barrier design is discussed. Differences between compartmented and non-compartmented rainscreen walls and the resulting loads on air barriers are reviewed. The differences between load carrying mechanisms of flexible and rigid air barrier materials are discussed. Air barrier systems employing materials such as gypsum board, polyethylene, rigid insulation and membranes are reviewed.

Structural design philosophies such as Limit States Design (LSD) are discussed for their relevance to air barrier design guidelines.

Structural review of air barrier systems is illustrated with examples. The report also discusses limitations in the current database of structural information of air barrier materials and provides recommendations for structural data necessary for structural design of air barriers are given.

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1. INTRODUCTION

The National Building Code of Canada requires that buildings are provided with an *effective* barrier to air exfiltration and air infiltration. The component(s) within a building envelope which provide "airtightness" for a building is called the "air barrier".

Air barriers are required in exterior vertical (walls) and horizontal planes (roofs, ceilings) of a building. This report concentrates on air barrier requirements for walls of buildings.

The purpose of this report is to introduce the design professional the "structural requirements" of air barriers. A variety of information, expertise and discussion will be necessary to establish a recommended practice or code for structural design of air barriers. This report will provide interim guidelines and a suggested framework for the development of final structural design recommendations for air barriers. The term "structural" refers to requirements such as strength, rigidity, accommodation of building movements and durability. To date, work on air barrier technology has concentrated on the air leakage process and the development of constructions which can fulfill the air barrier role. The current practice for air barrier design does not include consideration of structural requirements. Nevertheless, "structural" requirements for air barriers exist.

The National Building Code of Canada does not require that "air barriers" be engineered. The NBC requires that an effective barrier must be provided to air exfiltration and air infiltration. Designers are generally unaware that an air barrier may be subjected to significant air pressure due to wind effects on a building and that an air barrier will only be effective as long as it is able to resist these loads. Designers are also generally unaware that there are lesser magnitude but longer acting air pressures such as those due to stack effect which must be resisted by air barriers. Low magnitude constant loads can cause failure of some building materials due to creep. There are other low magnitude but constantly fluctuating loads such as daily wind gusting which can cause fatigue failure of some building materials.

Building codes contain requirements for structural adequacy of building cladding . The National Building Code of Canada provides guidance on the calculation of net design pressures to be used for exterior cladding. Net design pressures are the summation of exterior and interior pressures acting on the building. Design pressures have been derived for cladding with margins against structural failure, based primarily on the desire to eliminate danger to building inhabitants from being blown or sucked out of buildings (i.e. high-rise buildings) due to cladding failure or being impacted by falling failed cladding components. Consequently, some air barrier materials may be required by code to satisfy structural requirements as a result of being part of the building cladding. Precast concrete cladding in a face sealed approach is an example of air barrier material which has building code structural requirements. However, the "failures" which building codes protect against are events such as loss of load carrying capacity of cladding or its anchorage. Events such as failure of caulking which can be critical to the functioning of an air barrier are not covered by code structural requirements for cladding.

Air barriers whose failure does not compromise the load carrying capacity of building cladding do not currently have structural code requirements. Caulking for a face-sealed wall and air barriers within wall constructions for rainscreen walls are examples. The consequences of an air barrier failing within a wall construction does not pose the same public danger as failure of building cladding anchorage for example. Air barrier failure within a wall does not endanger the pedestrian or building occupants. Failure of an air barrier within a wall construction will result in an increase in air pressure loads acting on other planes within the wall such as the building cladding. However, since building cladding is required by code to be designed for air pressure loads, the failure of an air barrier should not result in building cladding failure.

Air barriers are structures and are subjected to air pressures from mechanical pressurization, stack effect and wind. When an air barrier within a wall construction fails due to being structurally overloaded it ceases to perform as an "air barrier". This can occur without detection with the likely consequences of accelerated rates of building envelope deterioration due to corrosion, freeze-thaw damage, efflorescence, etc. For an air barrier to be *effective* it must be capable of supporting the air pressure loads which will act on it during it's life.

The development of structural design requirements for air barriers will enable designers to better ensure that air barriers function for their intended life.

Some materials which act as air barriers are already the subject of design codes and procedures. Steel metal liners, precast and panel-in-place concrete and glass are some examples. Many other materials, however, are used as air barriers include plastics, gypsum board etc., for which design codes and procedures are not readily available. The design community will require a coherent, unified approach to design and specification of air barrier systems. The eventual goal should be the availability of an air barrier design handbook including design requirements, design procedures and design information on air barrier products. In the next section let us review:

- possible formats for air barrier design guidelines
- available information
- information to be gathered and developed
- interim guidelines which can be developed.

2. REQUIREMENTS OF AIR BARRIER DESIGN GUIDELINES

The National Building Code of Canada requires that an ***effective*** air barrier be provided. An effective air barrier is one which limits air leakage to acceptable amounts.

Acceptable value of air leakage are a function of:

- interior humidity levels
- interior comfort levels sought
- susceptibility of walls to condensation from humid air leakage
- ability of walls to drain moisture, susceptibility of wall construction damage due to moisture
- energy efficiency levels sought.

An effective air barrier can be provided by a single plane of airtightness or by the combined resistance to air flow of a number of planes within a wall. From a structural design perspective, it is better to deliberately introduce a single plane of greater air tightness than the rest; consider this plane to be the air barrier, and design it for the accompanying loads. Other relatively airtight planes within the wall will also experience air pressure loads which should be considered. However, one and only one plane within a wall should be designed to be the air barrier.

The purpose of structural design guidelines for air barriers is to ensure that:

Structural Integrity

1. The air barrier has acceptably low probability of failure during its design life. The following are examples of types of possible failures:
    - failure of material or connections due to extreme loads
    - fatigue failure of material or connections due to frequently occurring cyclic loads
    - failure of material or connections due to creep effects

Serviceability

2. The air barrier may have additional operational structural requirements.

The following are examples:

- Deflection or stiffness of air barrier is kept within set limits for commonly occurring loads. Deflection or stiffness requirements may be set in order to keep air barrier and thermal insulation in contact with each other. Deflection or stiffness limits may also be set to achieve a certain pressure-equalization performance of rainscreen walls.

Although both structural integrity and serviceability criteria will ultimately be of value in air barrier design, our first efforts must concentrate on assuring that air barriers maintain their structural integrity. Since the purpose of air barriers is to prevent air flow, one should consider all of the following as structural failures:

- failure of materials comprising air barrier
- failure of connections of air barrier material
- permanent deformation of air barrier material (e.g. around connections) allowing excessive air to leak through air barrier.

Structural failures can result from one-time application of rare extreme loads (ultimate loads) or cyclic or constant application of regularly occurring loads.

Throughout this report the term pressure should be understood to mean relative pressure. We are concerned with pressures superimposed on background barometric pressure, due to wind, stack effect, mechanical pressurization, etc. For the following discussions it is helpful to understand a couple of commonly used terms in structural engineering.

Until recently, most structures were designed using what is termed allowable stress or working stress design (ASD or WSD). In this design approach, loads representative of more everyday occurrence are used (called specified or working loads). A designer would calculate stresses due to the specified loads. The designer would then assure that there is an acceptable "factor of safety" between the ultimate stress the structure can withstand and the stress due to specified loads.

Structural design codes are being gradually changed to a format called limit states design (LSD) or ultimate strength design (USD). In limit state or ultimate strength design, the designer calculates a "factored" or "ultimate" load which is meant to represent a near upper bound on the loads the structure will experience during its lifetime. The designer also calculates "factored" or "ultimate" strengths which are lower bound values of member's ultimate strengths. A structure is considered adequate if its "factored strength" exceeds the "factored loads".

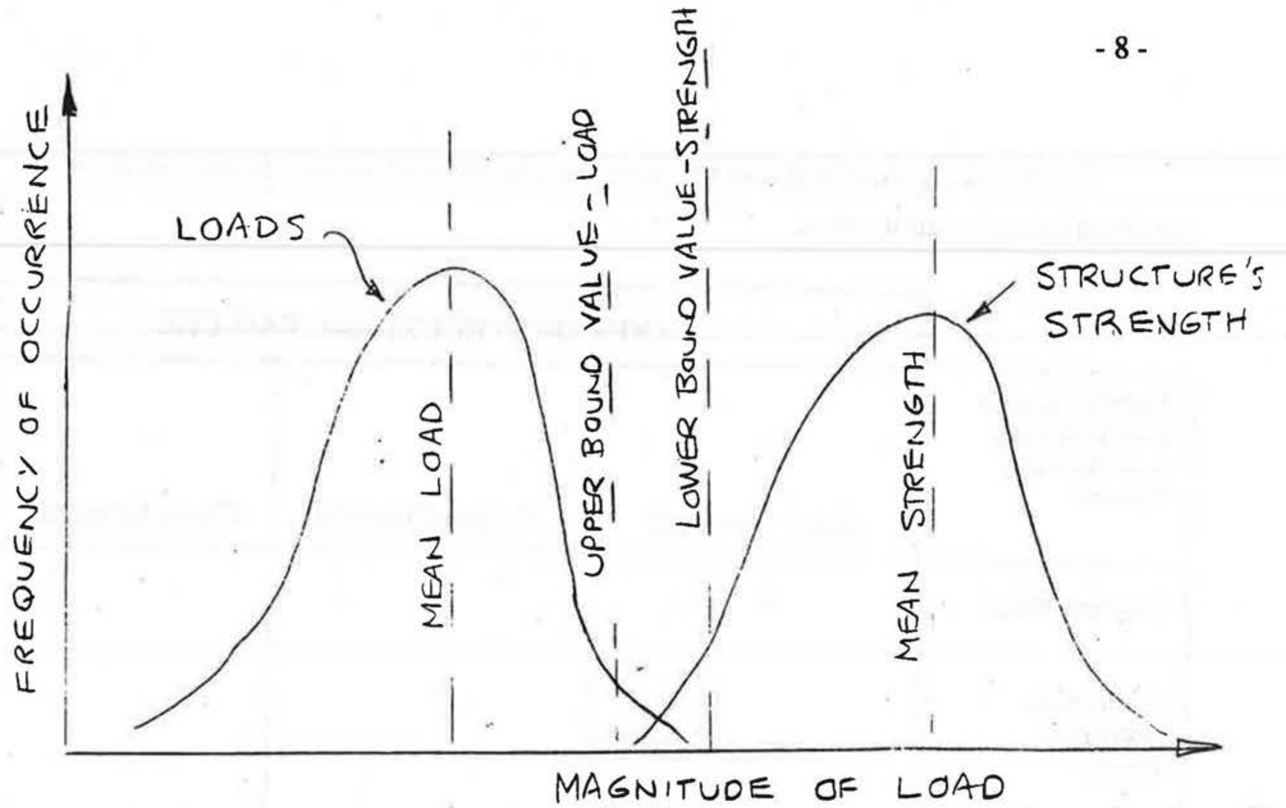
The authors advocate that structural design guidelines for air barriers be developed using the limit states approach.

The following chart indicates the principal type of loads which can contribute to structural failure of air barriers.

Type of Loads Contributing to Structural Failure	**TYPE OF STRUCTURAL FAILURE** **Static Strength**	 **Fatigue Strength**	 **Creep Strength**
Extreme Wind	•		
Commonly Occurring Winds		•	
Stack Effect	•		•
Mechanical Pressurization	•		•
Restraint to Thermal Expansion Contraction	•	•	•

Generally, air barriers in rainscreen walls are located on the warm side of insulation and are not subjected to significant thermal effects. Loads due to restraint of thermal movements are significant, however, for "face-seal" cladding.

The basic objective of structural design is to assure that there is an acceptably low probability that strengths of a structure (static, fatigue, creep) will be exceeded by the loads acting on the structure. A structural designer compares an upper bound value of loading with a lower bound value of structural strength to determine structural adequacy.



Note: small probability of failure when lower bound strength exceed's upper bound for loads.

Effect of Design Life

The values of loads chosen for air barrier designs are affected by:

- the required certainty that these loads will not be exceeded
- the design life of the air barrier.

The design life of an air barrier will affect:

- the magnitude of extreme wind acting on an air barrier
- the number of cycles of loading due to wind and thermal effects
- the duration of constant loading causing creep of air barrier materials.

Over the years design guidelines have been developed for conventional structural engineering materials such as, concrete, steel, aluminium, masonry and timber. It is not a forgone conclusion that the same margins of safety are appropriate for a completely different set of building materials which are being used as air barriers (gypsum board, certain types of insulation, membranes, etc.), and completely different consequences of failure.

Structural codes and building product standards must be carefully developed since their provisions can eliminate certain building materials from consideration, can lead to changes in building practice which affect costs, and can inhibit experimentation and product development. The wind loading provisions of the National Building Code of Canada, for cladding, should not be merely adapted for air barrier design. We believe that air barrier design guidelines should be developed which clarify insofar as is possible in the significant results of wind engineering. Given the variety of air barrier systems, design lives and consequence of failure; we believe a procedure should be readily available to designers which will allow the selection of wind loads with a given probability of exceedance for a given design life. This information is available but is not part of the National Building Code provisions.

Although this report principally deals with the application of NBC cladding wind loading provisions to air barrier, Section 7 discusses and illustrates code-based and alternative approaches to air barrier design for wind loading.

3. GENERAL DESCRIPTION OF LOADS ACTING ON AIR BARRIERS

Loads Acting Perpendicular to Air Barrier

An air barrier transmits air pressure loads to the wall structure. The wall structure in turn transmits the load to the building's structural frame. The causes of air pressures acting on air barriers are:

1. external and internal wind pressures resulting from wind effects,
2. internal pressures resulting from mechanical system operation, and
3. internal pressures resulting from stack effect.

Load Acting Parallel to Air Barrier

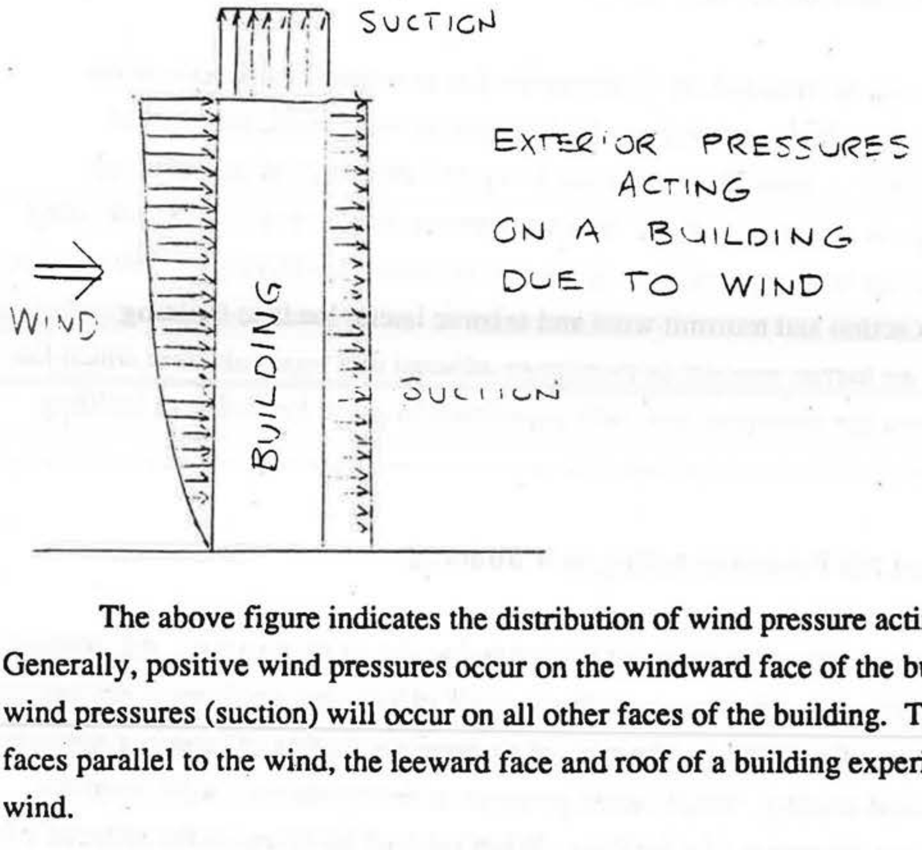
In-plane loads can be imposed on an air barrier due to overall deflections of the building's structural frame. Structural frames displace due to wind loads, differential displacement of foundations, thermal movements, creep and shrinkage of concrete, etc. Walls should be designed so that structural frame movements do not result in unanticipated loads being applied to the building cladding. However, some structures rely on wall cladding to provide diaphragm action and transmit wind and seismic lateral loads to building foundations. A rigid air barrier element or membrane adhered to a rigid substrate which has not been separated from the main structure, will experience in-plane loads due to building structure deflections.

Wind Induced Air Pressures Acting on a Building

The primary type of loading on an air barrier is that due to air pressure. Air pressure loads are exerted on air barriers due to wind effects, stack effects and mechanical equipment pressurizing the interior of a building. The type of air pressure loading of largest magnitude for an air barrier is wind loading. Wind causes pressure to be exerted on a wall assembly from both the exterior and interior of a building. Wind induced pressures in the order of 1.0 to 1.5 KPa occur very frequently (across building walls). During the lifetime of a building, it is not uncommon for pressures in excess of 3.0 KPa to act on a wall assembly.

Wind exerts forces on buildings and their components due to the fact that moving air has kinetic energy which will convert into potential energy in the form of air pressure when the flow of the air is obstructed. The velocity of moving air in the vicinity of a building is constantly changing. Consequently, a building and its components will be subjected to air pressures which are constantly varying in magnitude. At any instant, the wind velocity could be considered to vary about a mean wind speed. The deviations positive and negative from a mean windspeed are wind gusts. Some structural materials are susceptible to degradation due to constantly fluctuating loads (called fatigue). Wind has caused fatigue failure of structural components and their connections and needs to be considered in evaluating the suitability of an air barrier system.

The Nature of External Wind Pressure Acting on a Building



The above figure indicates the distribution of wind pressure acting on buildings. Generally, positive wind pressures occur on the windward face of the building and negative wind pressures (suction) will occur on all other faces of the building. Typically, the building faces parallel to the wind, the leeward face and roof of a building experience suction due to wind.

It is a very common misconception by the design community that materials on the exterior of a building envelope are subjected only to exterior wind effects and that materials on the interior face of building envelopes are subjected only to mechanical pressurization and stack effects.

Wind causes air pressures to be transmitted into the interior of a building. Building products throughout a wall construction will be subjected to air pressures which are determined by:

- the total pressure difference (ΔP) acting across a section of wall;
- the relative air permeabilities of materials within the wall; and
- the ability of air to flow laterally (horizontally or vertically) within the building products or deliberately introduced airspace (cavities) in the wall construction.

Air Pressures Inside a Building Due to Wind

Generally, information about overall wind loading contained in building codes is sufficient for overall design of all but unusual structures, (for which wind tunnel testing of models is required). External pressure loading coefficients for structural design purposes have been developed by wind tunnel testing of models made of air impermeable materials such as Plexiglass.

Wind tunnel and analytical studies have been done to try to quantify the internal pressures occurring in a building as a result of wind. The effects of openings such as open windows and doors on different faces of buildings have been investigated for their effect on internal pressures. The understanding of wind-induced internal pressures is far less complete than for external pressures, because these internal pressures are affected by complexity of flow between room, elevator shafts, etc.

Fortunately, for the purpose of overall structural building design, uncertainty regarding the magnitude of wind-induced internal pressure is not very important. Internal building pressures are self-equilibrating and do not cause a net lateral force on the building. However, internal building pressures due to wind can be a major contributor to loads acting on individual section of cladding (or air barrier). It is essential to include wind induced interior building pressures when calculating design loads for cladding or air barriers. The following information is provided in the National Building Code regarding interior building pressure coefficients.

Interior pressures	C_p
1. Openings mainly in windward wall	+0.7
2. Openings mainly in leeward wall	-0.5
3. Openings mainly in walls parallel to wind direction	-0.7
4. Openings uniformly distributed in all 4 walls	-0.3

How Building Envelopes Resist Air Pressure Loads

Once air pressure loads are transmitted into a wall, the load will be shared by structural layers in proportion to their relative stiffness, spans and connectors between layers. A designer can evaluate, for example, the proportion of wind load resisted by each of brick veneer and steel stud, without any understanding of the pressure gradient through the wall. The designer may erroneously assume, for example, that all the ΔP acting across the wall occurs at the brick veneer, that wind pressure is first resisted by the brick veneer of a brick veneer-steel stud wall and that masonry ties then transfer a portion of this applied load to the back-up steel stud wall. In fact, in a brick veneer-stud wall with an air barrier, a large percentage of the total ΔP for the wall occurs across the air barrier. This results in a large percentage of air pressure loads being first resisted at the air barrier. The air barrier then transfers the load to it's structure support (e.g. steel stud wall). Masonry ties will then share the applied load between brick veneer and steel stud back-up wall.

An incorrect understanding of where air pressure loads first act on a brick veneer/steel stud wall may lead to some erroneous assumptions about how masonry ties are acting (i.e. compression or tension) but would not be expected to adversely affect the structural adequacy of the wall.

The same comment does not hold true for air barriers. In assuring the survival of an air barrier, it is critical that the loads acting on it are realistically appraised. An erroneous assumption that external wind pressures are picked up entirely by the brick veneer (in the example just mentioned) would mean that the designer would be ignoring the effect of external wind pressures on the air barrier. There are examples in the field, of failures of air barriers located in the cavities of walls. These failures have been attributed to the effect of wind within the wall construction itself.

Concepts of Wind Engineering Useful to Design of Air Barriers

There are a few key concepts concerning the effects of wind within a building envelope construction which are useful for designers, namely:

1. For all practical purposes, the leakage area and openings in a building do not affect the external wind pressures acting on a building. However, leakage area and openings into a building significantly affect the interior pressures in a building.

   If the building envelope were completely airtight and rigid, no internal pressure would be caused by wind. However, all buildings will permit leakage of air through the walls, doors, windows, etc. Consequently, internal pressures develop in a building due to wind. The magnitude of internal pressure that occurs inside a building tends to be a pressure that balances the flow of air into and out of the internal volume. If leakage or flow into the internal volume is uniformly distributed around the building, the internal pressure will be close to the average of exterior pressures. If a dominant leakage area is located on one face of a building, the interior pressure will tend to equal the exterior pressure on that building face. The porosity of the building envelope controls how quickly changes in exterior pressure (wind gusts) are transmitted to the interior space. For gusts to *not* be transmitted to the interior volume, the building envelope must have no significant openings. An opening does not have to be very large to transmit gusts to an interior space.

   An opening or combination of openings on one face greater than the combined leakage areas of the rest of the building, enables wind gust effects to be transmitted to the interior of the building. One open window or door is usually sufficient to transmit wind gust effects to the interior of a building.

2. When lateral flow of air within wall construction does not occur one can calculate the static pressure gradient across a wall, using the air impermeabilities of layers with the wall. The net static air pressure applied to any individual component can be determined from the static pressure gradient across the wall.

3. Static pressure gradients across walls cannot be accurately estimated when lateral flow of air can occur within a wall assembly. When a wall has a cavity which is wide, a mean pressure will develop in the cavity will be that required to balance flow in and out of the cavity. When the wall has a narrow cavity however, there will be significant pressure losses resulting from the air flow within the cavity and there will be pressure gradients along the cavity.

4. Dynamic pressure gradients across walls cannot be accurately estimated when lateral flow of air can occur within a wall assembly.

5. Analytical techniques exist for estimating dynamic pressure gradients across walls when lateral flow of air is prevented (compartmentalized rainscreen wall)[1].

6. A building which has ben sealed at the exterior against water and air penetration is said to have a "face seal". An air barrier located on the exterior of the building (face seal) is subjected to the full exterior wind pressures. The wind loading provisions of the building codes have been specifically developed for this type of building where the most resistant plane to air passage plane is located on the exterior of the building envelopes. Rainscreen wall construction is so varied that it is unlikely that wind loading provisions can be developed to enable accurate estimation of wind induced pressure gradients across rainscreen walls, with the exception of compartmentalized rainscreen walls.

Field measurements and wind tunnel tests have been conducted to gather information on how wind induced air pressure loads are applied to rainscreen walls of buildings.

Field Measurements and Wind Tunnel Tests

Field measurements and wind tunnel tests of wall constructions with non-compartmentalized airspaces show a variety of results. Field tests on vinyl clad wood frame walls, in which wind is relatively free to flow between cladding and an inner plane of air tightness, exhibited wind load being applied 50% to the rainscreen (vinyl cladding) and 50% to the back-up wall (sheathing, gypsum, vapour barrier). Field tests on a brick veneer steel stud wall without any compartmentalization to restrict lateral flow in the cavity exhibited 70% of wind load being applied to the rainscreen (brick veneer) with the balance being applied to the back-up wall. Field tests on compartmentalized precast rainscreen walls have indicated that at times 100% of the wind load was being resisted by the inner panel. At other times 75% of the load was being resisted by the outer panel.[2].

Wind tunnel studies attempting to simulate rainscreens with little compartmentalization have reported as high as 100% of the total wind pressure being applied to the rainscreen nearer to building corners, diminishing to 80% of the total wind pressure in central areas. Inner back-up wall were reported to experience 85% of the total wind load at certain times [4].

From the limited experimental information available regarding wind effects on rainscreen walls, one has to conclude that air barriers in rainscreen walls can be subjected to significant percentage of wind pressures (50% to 100% of total wind pressure). The better the construction industry is able to provide an effective air barrier, the greater the likelihood that the air barrier will need to withstand 100% of the total wind pressures.

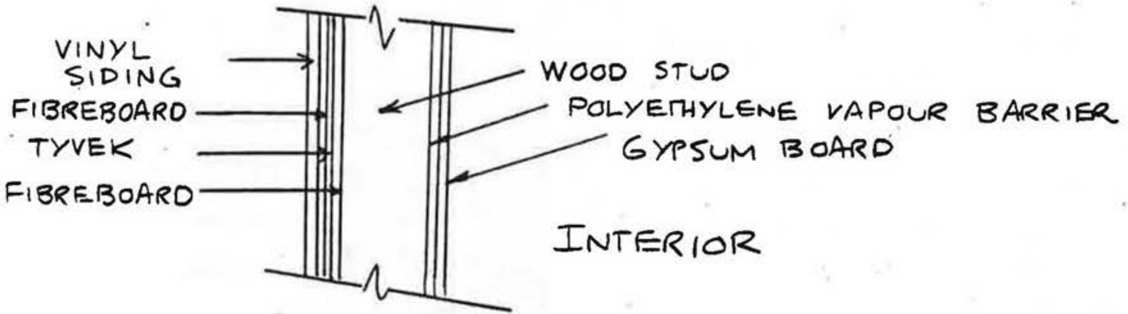
Based on available information, we recommend that air barriers be designed for 100% of wind pressures in addition to stack effect and mechanical pressurization pressures. Building cladding should continue to be designed for 100% of wind pressures.

4. AIR PRESSURE LOAD PATHS FOR EXTERIOR WALLS

Air barriers and their structural requirements must be discussed by considering specific building envelope constructions and how they resist air pressure loads. This chapter will focus on common wall systems and identify the load path followed by air pressure loads to the main building structures. The following wall systems will be discussed briefly.

- Clad Wood Stud Frame
- Brick Veneer/Steel Stud Wall
- Brick Veneer/Concrete Masonry Wall
- Exterior Insulation Finishing System

Clad Wood Frame Walls



CROSS-SECTION THROUGH WALL

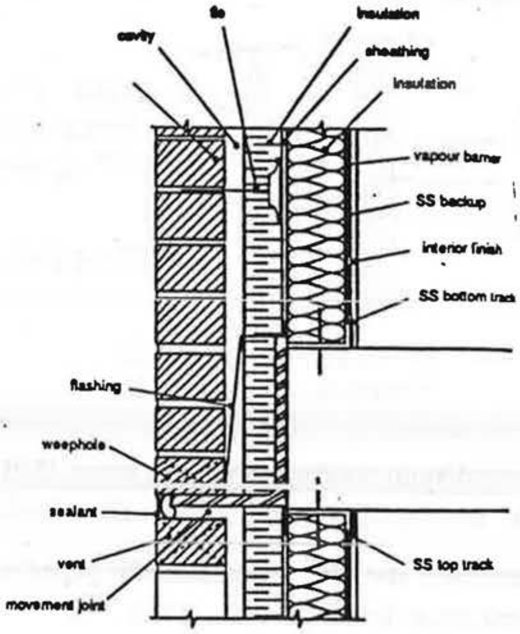
Comments:

- Fibreboard/spun bonded polyolefin paper (SPP)/Fibreboard provides air barrier. Air barrier transmits air pressure loads to studs.
- Of fibreboard and SPP paper, the SPP paper is more impermeable to air and will first resist the air pressure loads.
- The SPP paper is prevented from displacing in either direction by the fibreboard sheathing.
- No deliberate restriction to lateral flow between vinyl siding and air barrier. Therefore, expect a portion of mean and gust wind loads to be resisted by air barrier. However, not possible to analytically predict peak percentage of total Δ P which will act across vinyl siding and air barrier planes respectively.

Conclusion:

- Fibreboard and its connections are required to be structurally adequate for full air pressure loads
- No structural requirements for Tyvek paper since sandwiched between two planes of material which are capable of transmitting load to studs.
- Fasteners of fibreboard to stud wall transmit suction loads on air barrier to studs. Fasteners of fibreboard also transmit shear loads since fibreboard is typically active as "shear wall" of structure. Fasteners must transmit combination of shear and tension.

Brick Veneer/Steel Stud Wall



Comments:

- Air barriers located on exterior of steel stud can consist of air impermeable sheathing such as taped gypsum board, or membrane applied to a sheathing material.
- Alternatively, air barriers can be located on inside of steel stud using interior gypsum finish.
- Air pressure acting on air barrier are transmitted from air barrier to supporting material if any, and then to steel studs. The steel studs transmit a portion of applied load to their top and bottom tracks and a portion through the brick tie back to the brick veneer. In brick veneer construction without an air barrier, the most resistant plane to air movement can be the brick veneer. In such a

case, the majority of total air pressure load can be applied to the brick veneer. However, when an air barrier is present, it will be more resistant to air flow than the brick veneer. The result is that the air barrier must be able to resist total air pressure load including wind, stack effect, mechanical pressurization and interior wind induced pressures. Load transmitted to rest of structure by a combination of brick veneer and steel studs dependent on support conditions of each wythe, stiffness of each wythe and their interconnection. Ties between wythes have play in them which affects load sharing between brick and steel stud.

- Considerable debate over how stiff steel stud should be able to reduce possibility of brick veneer cracking with corresponding increase in rain penetration. Debate also over whether stiffening effect of sheathing and interior finish should be included in evaluating stiffness of steel stud back-up wall.
- Shelf angles restrict lateral flow of air within cavity in vertical direction, although not provided for that purpose.
- Expect a significant portion of mean and gust wind loads to be resisted by air barrier. However, not possible to analytically predict peak percentage of Δ P which will act across brick veneer and air barrier plane respectively.
- When air permeable insulation used, do not expect net loads to act on insulation tending to displace insulation into the cavity.
- When air impermeable insulation materials are used such as extruded polystyrene, air flow between joints occurs when sudden change in cavity pressure is caused by wind gusting. Air will flow between joints of insulation material until air pressure on either side of insulation is equal. While this is occurring, the insulation material is subjected to net load which can displace the insulation material into the cavity.

Conclusions:

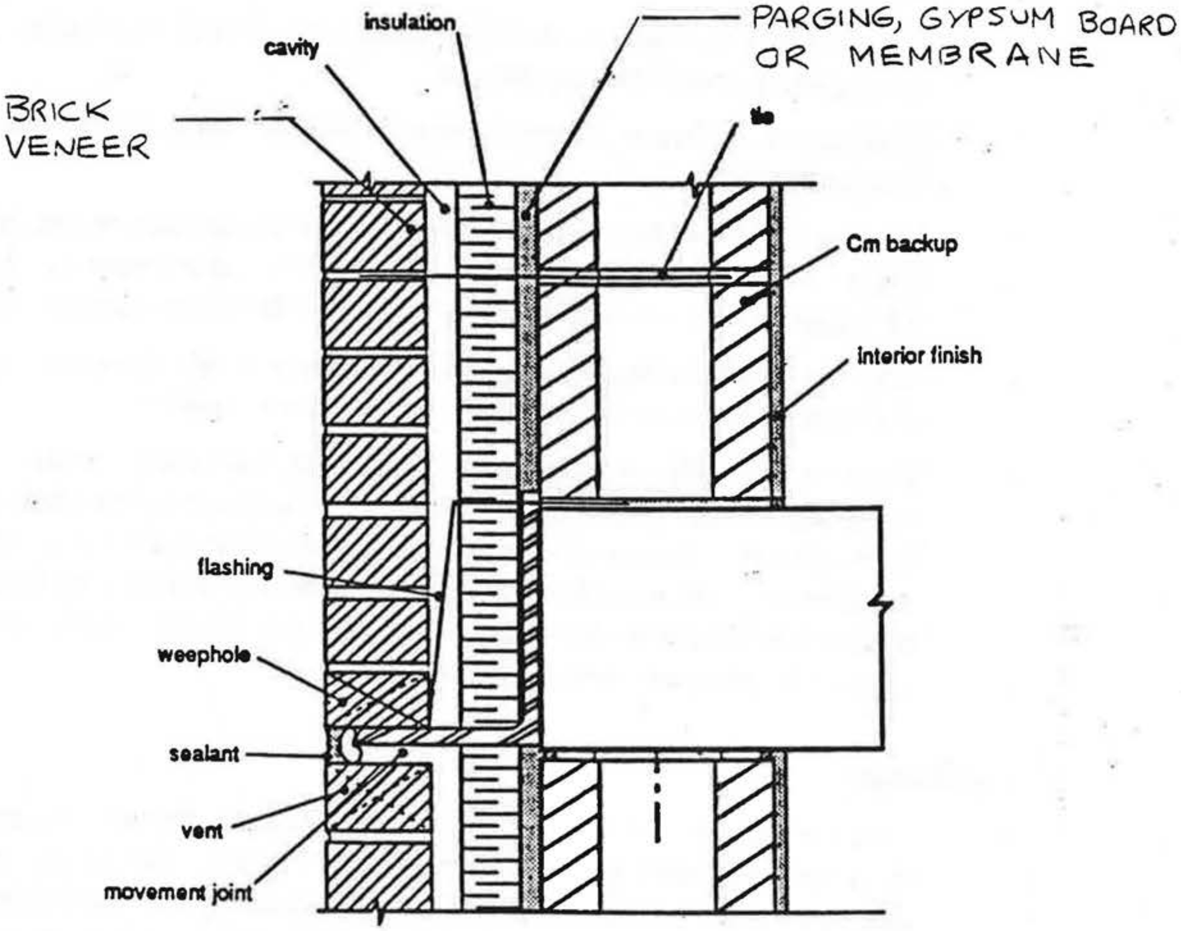
- Air barriers should be capable of transmitting total air pressure loads to steel stud back-up wall.
- Fastening of air barrier material or its substrate to steel stud by mechanical fasteners must hold air barrier material to the stud when outward directed air pressure loads are acting.
- Insulation can also be subjected to significant transient air pressure loads due to wind gusting. Insulation and its fastening system should be structurally capable of resisting gust portion of wind loads.

- Wall system can be converted into pressure-equalized rainscreen design by adding compartmentalization. Attempts at pressure equalization will be unsuccessful if pressure changes within cavity are able to change cavity volume by changing distance between brick wythe and steel stud due to "play" in masonry ties.
- To get improve resistance to rain penetration through brick veneer need to do the following:
  1) compartmentalize cavity as necessary prerequisite for pressure equalization.
  2) provide air barrier on steel studs which does not deflect appreciably between studs, because changes in cavity volume would prevent pressure-equalization from occurring.
  3) limit flexibility or play in ties between brick veneer and steel stud so that pressurization of cavity is not prevented by pressure-induced changes to volume of cavity.
  4) provide sufficiently rigid back-up wall to prevent excessive cracking of brick veneer due to applied wind loads.
- Considerable work has been done in modelling of structural response of brick veneer/steel stud wall systems. Work has also been done on modelling the effect structural response of wall systems has on the pressure equalization process.

  These two efforts could be combined in an analytical and experimental study of the pressure equalization characteristics of brick veneer/steel stud walls which have been compartmentalized. In particular, the effect of the following factors on pressure equalization (and hence rain penetration) could be studied:

  - stiffness of steel stud system
  - "play" and flexibility of connectors between steel studs and brick veneer
  - stiffening effect of sheathing
  - stiffness of air barrier spanning between studs

Brick Veneer/Concrete Masonry Wall



Comments:

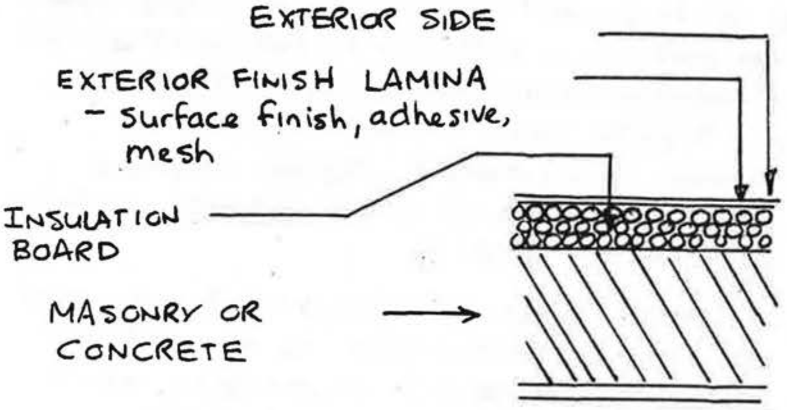
- Parging, gypsum board or membrane applied to exterior of concrete block can act as air barrier. Alternatively, interior finish on concrete masonry unit could be installed to act as air barrier.
- Load will be transferred from air barrier to concrete masonry block by direct bearing, adhesion or mechanical fasteners connecting air barrier material to concrete block.
- Load will be transmitted to rest of structure by combination of brick veneer and concrete masonry. Load sharing dependent on support conditions and stiffness of each wythe, and their interconnection. Generally, rigid tie between wythes is provided with ladder or truss type joint reinforcing.

- Generally concrete block many times stiffer than brick veneer and concrete masonry takes entire lateral load. Cracking of brick veneer due to wind loads unlikely to occur.
- Shelf angles restrict lateral flow of air within cavity in vertical direction although not provided for that purpose.
- Generally, no deliberate attempts have been made to restrict lateral flow horizontally within the cavity.
- Expect a significant portion of mean and gust wind loads to be resisted by air barrier. However, not possible to analytically predict peak percentage of total Δ P which will act across brick veneer and air barrier planes respectively.
- When air impermeable insulation used, net loads on insulation will occur tending to displace insulation into the cavity are not expected.
- When air permeable insulation materials are used, net loads on insulation such as extruded polystyrene or air flow between joints occurs when sudden change in cavity pressure is caused by wind gusting. Air will flow between joints of insulation material, until the air pressure on either side of insulation is equal. While this is occurring the insulation is subjected to net load which can displace the insulation material into the cavity.

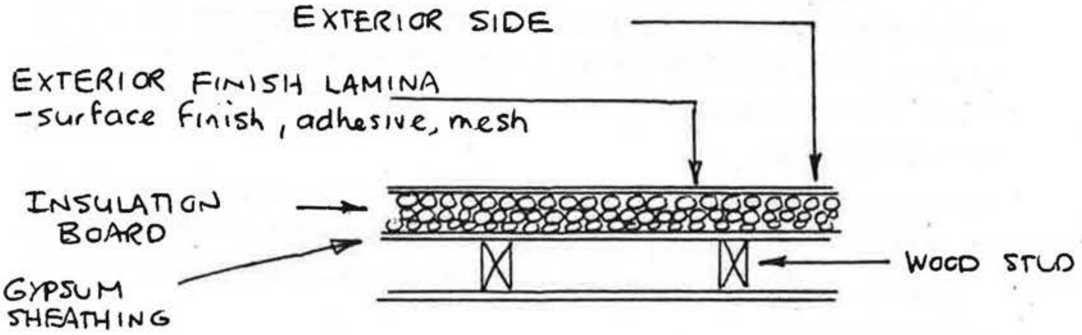
Conclusions:

- Air barrier should be capable of transmitting full wind effects to concrete block wall. Fastening of air barrier to concrete block whether it is by bonding (e.g. parging gypsum, modified bituminous membrane) or by mechanical fasteners (e.g. gypsum) must hold air barrier material on the block when outward directed air pressure loads are acting.
- Insulation can also be subjected to significant transient air pressure loads due to wind gusting Insulation and its fastening system should be structurally capable of resisting gust portion of wind loads.
- Wall system can be converted into pressure-equalized rainscreen design by adding compartmentalization. Wall system is suitable for pressure equalization since no problems expected with pressurization of cavity due to flexibility of either brick or concrete wythes or their interconnection i.e. pressure change within cavity cannot change volume of cavity significantly.

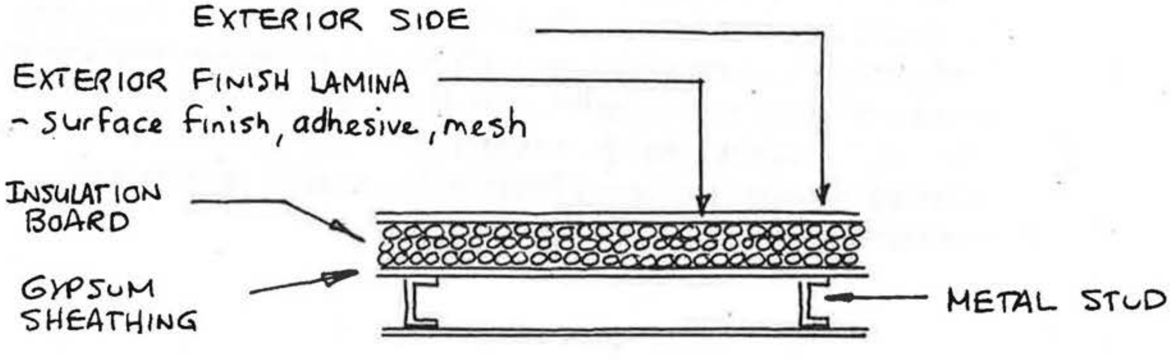
EXTERIOR INSULATION FINISH SYSTEMS



MASONRY OR CONCRETE WALL



WOOD STUD WALL



METAL STUD WALL

Exterior Insulation Finishing Systems

Comments:

- Exterior insulation finishing systems (EIFS) are proprietary cladding systems consisting of exterior lamina of a cementitious surface finish, an adhesive and a mesh all bonded to insulation board (extruded polystyrene in one system, expanded polystyrene in another system). The insulation board is mechanically or adhesively fastened to an underlying exterior sheathing substrate such as gypsum board, plywood, or cement board spanning between studs or directly to a masonry or concrete wall.
- Of the materials mentioned above, all can contribute to provide an air barrier function. The cementitious surface finish provides resistance to air flow similar to parging. Extruded polystyrene used in one proprietary system is itself impervious to air flow. Expanded polystyrene used in exterior insulation finishing system can have varying degrees of resistance to air flows. Typically, extruded polystyrene when used in EIF systems is typically of the denser grades which offer significant resistance to air flow. The substrate material to which exterior insulation finishing systems are applied can be very resistant to air flow such as cement board, plywood or gypsum board. The substrate can also be relatively air permeable such as masonry block construction.
- The only plane at which deliberate attempts are made to provide a continuity of air impermeable material is at the exterior. Joints between adjacent panels of exterior finished insulation board are typically caulked to provide a "face-seal" air barrier.
- The gradient of Δ P across an exterior insulation finish system will be very complex when there is defective or missing caulking between insulation boards and there is no dominant plane of airtightness. However, the intended load path for EIF systems is that outwardly directed air pressure loads (suction on the exterior) are transmitted first to the lamina, from the lamina to the insulation by adhesion, from the insulation board to the substrate by adhesion/mechanical anchorage. Inwardly directed air pressure loads are transmitted by direct bearing of materials.

Conclusions:

- The load path is not complicated and relies on each ply of the assembly being properly connected. Structural tests of exterior insulation finish systems in which joints are properly sealed, are able in one test to verify the component material strengths, and the adequacy of their joining methods.
- It is important in such systems that sheathing substrate used as a base for the EIF system is adequately fastened to the wall structure (e.g. steel studs). One of the concerns with any system (EIF or otherwise) which transfers loads using gypsum board, is that the gypsum board is kept from being wet. Manufacturers of gypsum board do not report specific effects that humidity has on gypsum board strength but do caution that gypsum board does lose its strength when wet. Also of concern with gypsum board is the effect of humidity and/or board wetness on fastener pullout capacities. Consequently, some manufacturers of exterior insulation finishing system do suggest that other materials such as cement board may be a more appropriate substrate than gypsum board for these systems.

5. MAGNITUDE OF AIR PRESSURE LOADS ACTING ON AIR BARRIER

As discussed earlier, there are three main causes of air pressure loading acting on "air barriers"; stack effect, mechanical pressurization of building interior and wind effects. Of these, stack effect and mechanical pressurization are loads which are of small magnitude but can act for long periods of time on an air barrier. Stack effect and mechanical pressurization are expected to be main causes of creep problems with air barrier materials and particularly with sealants. Peak wind loads and cyclic wind loading are the loads expected to able to cause structural failure of air barriers by exceeding adhesive strength, mechanical fastener strength, or material strength.

Loads on Air Barrier due to Stack Effect or Mechanical Pressurization

The Canada Mortgage and Housing Corporation (CMHC) currently has a project underway designed to provide specific guidance on effect of sustained loads on materials and sealants used in air barrier technology. The results of this test program are expected to provide some guidance regarding this area of concern.

Magnitude and Duration of Stack Effect

The parameters affecting the magnitude of air pressures due to stack effect are:

- ambient air pressure,
- difference in temperature between inside and outside air,
- distribution of openings over height of building,
- internal partitioning of building. Multi storey buildings have interior partitions that are not airtight. Passage for airflow exist through floors such as stairwells, elevators, etc., and these affect the distribution of internal pressure within a building.
- building height.

Estimation of stack effect pressures including all the above mentioned factors is too involved for design purposes. A designer is more interested in establishing for a given building location and building height a reasonable conservative estimate of magnitude and duration of stack effect load.

In a building which has no internal partitions, stack effect pressure will increase linearly with distance away from the neutral plane. The neutral plane is the elevation on the building where internal and exterior ambient pressures are equal. If a building has no dominant openings (e.g. equal openings top and bottom then the internal and external pressures will be equal at the mid-height of the building. In such a case, the maximum stack effect pressure will be based on one-half the total height of the building. When a building has dominant openings at the bottom, however, then the internal pressure and external pressure will be equal at the bottom, and maximum stack effect pressure will be based on the total height of the building.

Buildings in which there is complete isolation of each storey with balanced openings to the exterior, the stack effect pressure will be negligible and based on 1/2 the storey height.

In tall buildings, it is known that the neutral plane varies from 0.3 to 0.7 of the total building height. For houses, the neutral plane is usually above building mid-height and can be near the top of the building. For design purposes, it is reasonable to use 70% of the total building height in computing upper bounds on stack effect pressures. Stack effect pressure is approximately 0.14 Pa/K/storey for a typical 3 m storey height.

Climatic Data contained in the National Building Code of Canada contains "design temperature" for January and July, which can be used to establish conservative values for stack effect pressures.

These design temperatures are rarely exceeded during their respective months and can be used to conservatively estimate magnitude of stack effect pressures. Interior building temperature can be taken to be 21°C. A January design temperature of -40°C can be conservatively used for the entire country with few exceptions (Northwest Territories, Yukon). The temperature will drop below this value for less than 2.5% of the hours in January across the country. The corresponding upper bound on stack effect pressure is 61° x 0.14 Pa/storey = 8.5 Pa/storey. Similarly, during the summer, a July design temperature of 30°C is an upper bound for the entire country. The stack effect pressure during July will be less than (30 - 21) x 0.14 Pa/storey = 1.3 Pa/storey.

Using 70% of the total building height as the maximum vertical distance from the neutral plane to a location in the building, the following maximum stack effect pressure are estimated.

Building Height (storeys)	**Suggested Max. Stack Effect Pressure for Design**
3	18 Pa
10	60 Pa
20	120 Pa
50	300 Pa

Without a detailed study, it would seem reasonable to conservatively require an air barrier to withstand stack effect pressure of the magnitudes indicated above for approximately 150 days per year. (At any location, one can divide the degree days below 18°C by the difference between design temperature and 18°C, and the resulting equivalent number of days at the January design temperatures is in the range 120 - 150). For a building life of 50 years, this implies 20 years of continuous application of the above stack effect pressures. Some building materials experience continued deformation due to applied loads which act for long durations. This phenomenon is known as creep. Stack effect pressures do act on an air barrier for long durations. Therefore, it is essential that air barrier materials and sealants do not creep at these low levels of sustained pressures.

If a material or sealant experiences creep at these low magnitudes of applied pressure, it is unsuitable for use in air barrier construction.

Magnitude and Duration of Mechanical Pressurization

Building interiors are pressurized for a number of reasons. Portions of buildings are pressurized for smoke control in the event of fire. In tall buildings, where the main entrance is at ground level, it is desirable to have the interior and exterior pressure balanced at this level to facilitate opening doors, etc. Consequently, many buildings are positively pressurized to bring the neutral plane from near building mid-height to ground level. Whereas, naturally, 70% of the building height would be conservative to use in estimating stack effect pressures. The combined effect of stack effect and mechanical pressurization can be thought of as a stack effect pressure based on the neutral plane being located at the base of a building.

The following levels of loading for combined effect of natural stack effect and mechanical pressurization are based on the mechanical pressurization moving the neutral plane to the base of the building.

Building Height (storey)	**Suggested Max. Combined Effect Stack Effect & Mechanical Pressurization**
3	25 Pa
10	85 Pa
20	170 Pa
50	425 Pa

Again these loads are expected to act continuously for approximately the length of winter i.e. (120 - 150 days). For a mechanically pressurized building, this would suggest that in a 50 year building life, the air barrier would be subjected to 20 years of continuous application of the above combined stack effect/mechanical pressurization air pressure.

Limitations of Code-Based Wind Pressure Calculations

An air barrier must be able to withstand constant air pressure loads such as stack effect and mechanical pressurization acting for long durations. An air barrier must also be able to withstand widely fluctuating air pressures due to wind effects.

Canadian wind loading data is derived from long term meteorological records of average hourly wind velocities. By collecting data for a given period of time, and using accepted probability distributions for extreme values of physical phenomenon (e.g. Wiebull distribution extreme value analysis), it is possible to estimate the value of wind velocity that can be expected with an established degree of certainty to not be exceeded during any given period. Accordingly, a so-called 10 year return wind is the average hourly wind which is expected to be exceeded only once every 10 years. In any randomly selected year, there is a relatively high chance ($^1/_{10}$) of this wind velocity being exceeded.

Code-Based Air Pressure Loads Due to Wind

The following approach will be taken in calculating "ultimate" or "factored" wind loads on air barriers:

- exterior pressure coefficients for cladding are used for air barrier as well. At the present time, there is a lack of test data and no reliable analytical method to determine pressure coefficients specifically for cavities in rainscreen walls.
- "ultimate" or "factored"loads will be determined which are not site specific but generally applicable across the country.

The key factors affecting wind pressure on a structure are:

- wind velocity
- pressure coefficients for specific building subject to wind

Information on wind velocity at a given site is based on meteorological records. Information on pressure coefficients for buildings are based on wind tunnel tests of scale models of the building in question or similar shaped buildings.

Pressures due to wind are proportional to the square of wind velocity. Therefore, pressures due to wind are highly sensitive to the magnitude of wind velocity.

A designer's intent is to ensure that with a high probability, a structure's strength exceeds the extreme loads the structure may experience during its life. A designer is interested to know the value of load which has a 5% chance for example, of being exceeded in a 50 year period.

The National Building Code approach to wind loading is not structured to allow designers the option of choosing wind pressures appropriate for a given design life and probability of exceedance.

The code approach to wind loading enables one to calculate a so-called "ultimate" or "factored" wind pressure appropriate for either cladding (based on 10 year return wind) general structures (based on 30 year return wind) post-disaster buildings (based on 100 year return winds). To arrive at an "ultimate" or "factored" design pressure, a series of factors are applied to the stagnation pressure of the 10, 30 or 100 year return wind velocity. These factors cover uncertainties in:

- pressure coefficients
- uncertainty in how wind velocity varies with distance above grade
- uncertainty in using meteorological records at a specific site for nearby sites
- uncertainty in meteorological records and practice of using extreme value analysis to predict extreme values for periods longer than meteorological records to date, etc.

Nothwithstanding the complexity of wind engineering, it should be possible to have available to a designer, ultimate wind pressure for various design lives and various probability of exceedance. This information is particularly helpful in assessing how deficient current non-engineered air barriers may be. Section 7 of this report will provide examples of the types of calculations which can be done to "estimate" ultimate wind pressures for specific design lives and probabilities of exceedance.

Advantage can also be taken of the fact that extreme wind data for a site is often collected and analyzed without differentiating between different wind directions.

Often a site has a predominant wind direction which is the only direction likely to experience high values of wind pressure. It is possible to design the cladding or air barriers of a structure for extreme winds for each of the eight compass directions individually and the result may be that only the cladding or air barrier facing the predominant wind direction is governed by the higher wind velocities for the site. This approach has been applied in determining glass thicknesses requirements on some high rise building projects.

The code approach to exterior cladding design for wind pressures has been successful in the sense that exterior cladding failure due to wind is a rare event. Code wind loads have to date been used in conjunction with only traditional cladding materials (steel, concrete, aluminum, glass, etc.). It is not a foregone conclusion that the code based wind loads will work as well with cladding on air barriers designed in different materials. In addition, the consequence of failure of an air barrier inside a wall are different than that of exterior cladding breaking or detaching from a building.

For air barriers that are located on the inside of a building, where structural failure of an air barrier would be evident and thus be repaired, it is not unreasonable to design for lower wind pressures and accept a higher risk of failure during a building life.

More caution is warranted in the selection of design wind pressures for air barriers that are concealed within wall construction and whose failure may only be evident as a result of ensuing visible deterioration of the building cladding e.g. efflorescence of bricks, etc.

Given that no standard exists at present, as a starting point, it would seem reasonable to determine what change in air barrier materials and fastening would be required to meet the wind loading requirements currently required by NBC for cladding elements.

Let us start by determining wind loading requirements for cladding which are generally applicable across the country. A wind velocity of 115 km/h is expected to be exceeded on average only once every 10 years for all but 15 of 638 wind data locations in the country. The reference wind pressure used in calculations of wind pressures on a building is called the stagnation pressure and is the pressure that results from bringing wind at a given velocity to rest. A 115 km/h wind has a stagnation pressure of approximately 650 Pa.

The calculation of actual pressure that a cladding element should be designed for is a series of modifications to the stagnation pressure of the selected extreme hourly average wind. The following section describes the derivation of NBC wind pressure loads which can be applied to "air barriers".

Discussion of National Building Code Wind Loading

The National Building Code of Canada provides information on wind load pressures for design of primary structural and secondary structural members and cladding should be designed. Using the code, exterior and interior pressures due to wind can be calculated for a particular building based on wind data tabulated for that particular site.

Specified Exterior wind pressure is given by the NBC code as:

P_{ext} = $q\, C_g\, C_e\, C_{p\,EXT}$
q. = undefined by code at this date for air barriers, taken to be $q_{1/10}$
C_g = 2.5 for cladding, secondary structural members
= 2.0 for primary structural system
= undefined by code at this date for air barriers, taken to be 2.5 at this time for air barrier

C_e is an exposure factor which varies from .9 to 2.0 depending on the elevation above ground at which wind pressures are being calculated. Strictly speaking, the NBC recommends using building mid height in calculating external wind pressures on the leeward face of a building. For simplicity, leeward wind pressures are calculated in this report with C_e corresponding to the height of the point in question.

$C_{p\ EXT}$ generally varies from - .5 to + .8 for exterior pressures and is the ratio of wind pressure acting on a surface to the stagnation pressure that would occur if the dynamic energy of the wind were fully converted to static pressure. There are localized areas of buildings, particularly at corners where higher C_p may act. The National Building Code, however, does not require cladding elements to be designed for an absolute value of $C_p\ C_g$ exceeding 2.

The C_g factor accounts for the deviation in wind velocity that occurs from the recorded hourly wind speed. The fact that C_g is higher for secondary structural members and cladding ($C_g = 2.5$) than for overall structure ($C_g = 2.0$) reflects the fact that the local area of a building experience greater fluctuation in wind induced pressure, than pressures averaged over entire faces of a building.

Specified interior wind pressure is given by the NBC code as:

P_{int} = $q\ C_g\ C_e\ C_{p\ INS}$

q = undefined by code at this date for air barriers, taken to be $q_{1/10}$

C_g = 2.5 for cladding, secondary structural members

= 2.0 for primary structural system

= undefined by code at this time for air barriers, taken to be 2.5 for air barriers

C_e = is calculated using building mid height for interior pressures. For simplicity in arriving at generally applicable wind pressures for air barrier design, interior pressures are calculated using C_e based on the elevation of the point in question

Structural codes typically upwardly adjust specified wind pressures by a factor of 1.5 (use of 1.5 load factor for wind) to obtain a wind pressure with smaller percentages of being exceeded during the design life. This wind load is called an "ultimate" or "factored"load.

The load factor of 1.5 also allows for uncertainties in wind velocities, pressure coefficients and gust factors in the code formulation. Wind loads contained in building codes have not been explicitly developed to ensure that for a given building life, there is a known acceptably low probability of exceedance. Rather, based on the number of failures occurring due to wind loading, it would appear that the code value are conservative.

Resultant "Ultimate" or "Factored" Internal and External Pressure Due to Wind

$$\underset{\substack{\text{(INWARDS)}\\ \text{"ULTIMATE}\\ \text{FACTORED"}}}{P_{\text{RESULTANT}}} = \underset{\text{"SPECIFIED"}}{(\underset{\text{(inwards)}}{P_{\text{EXTERIOR}}} + \underset{\text{(inwards)}}{P_{\text{INTERIOR}}})} \times \underset{\text{"LOAD FACTOR"}}{1.5}$$

$$= q\, C_e\, (C_g = 2.5)(C_p = .8 + .3) \times 1.5$$

$$= q\, C_e\, (C_g = 2.5)(C_p = 1.1) \times 1.5$$

$$\underset{\substack{\text{(OUTWARDS)}\\ \text{"ULTIMATE}\\ \text{FACTORED"}}}{P_{\text{RESULTANT}}} = \underset{\text{"SPECIFIED"}}{(\underset{\text{(outwards)}}{P_{\text{EXTERIOR}}} + \underset{\text{(outwards)}}{P_{\text{INTERIOR}}})} \times 1.5$$

$$= q\, C_e\, (C_g = 2.5)(C_p = .7 + .3) \times 1.5$$

$$= q\, C_e\, (C_g = 2.5)(C_p = 1.0) \times 1.5$$

These wind loads are based on the wind pressure coefficients from Table Fig. B-10 of the NBC. The lower pressure coefficients for low rise buildings would be applicable in certain specific cases. The internal pressures included are based on openable windows and doors, which in general would be expected to be uniformly distributed on residential buildings.

From the climatic wind data values, $q_{1/10}$ of .65 KPa could be conservatively used for the vast majority of locations within Canada. The corresponding ultimate wind pressure for the air barrier based on use of $q_{1/10}$ = .65 KPa would be:

$$P_{\text{INWARDS}} = (.65\ \text{KPa})\, C_e\, (C_g = 2.5)(1.1) \times 1.5$$

$$= 2.7\ \text{KPa}\ (C_e)$$

$$P_{\text{OUTWARDS}} = (.65\ \text{KPa})\, C_e\, (C_g = 2.5)(1.0) \times 1.5$$

$$= 2.45\ \text{KPa}\ (C_e)$$

C_e can vary from 0.9 for near the ground (0 to 6 m) to 2.0 for upper floors in high rise structures (240 to 400 m). The variation in wind pressure due to height must be accounted for in recommendations or design loads.

For residential structures most buildings would be less than 20 storeys or approximately 64 meters above grade. We think it practical to give design loads for low rise buildings (3 storey or less) using $C_e = 1.0$ and for apartment buildings up to 20 storeys based on $C_e = 1.4$. Therefore, air barriers in low rise residential buildings must be able to withstand ultimated wind loads of approximately +2.7 KPa, -2.45 KPa, to satisfy code-based cladding design requirements across the cavity. Air barriers in buildings up to twenty storeys would need to withstand ultimate wind loads of +3.8 KPa, -3.4 KPa.

Ultimate or Factored

The following code-derived "factored" wind loads could be used across Canada for evaluation of air barriers:

Ht. of Air Barrier Above Ground	Inward Acting Wind Load Pa	Outward Acting Wind Load Pa
0 to 6 m	2400	2200
6 to 12 m	2700	2400
12 to 20 m	3000	2650
20 to 30 m	3250	2900
30 to 44 m	3500	3100
44 to 64 m	3800	3400

The above wind loads have been calculated on the following basis:

- Using NBC, using extreme wind values which are exceeded at very few locations within Canada (e.g. 15 out of 638 locations listed in Climatic Data for Canada, these locations are in remote northern communities).
- Gust factor appropriate for cladding design has been used for both exterior and interior pressures (Cg = 2.5). Gust factor was applied to interior building pressure because typical residential construction has openable windows and balcony doors.
- Pressure coefficients used were those for general use in structural design. Low building pressure coefficients were not used.

- Interior pressure coefficient used were those for buildings with leakage areas uniformly distributed on all walls.
- Assumed that 100% of Δ P acting across a wall, is applied to the air barrier. It is known that in many cases, this will be conservative. However, an analytical procedure does not currently exist which enables a designer to establish proportion of wind pressures which will act on air barriers, particularly when lateral flow within a cavity wall is occurring. Also, the expected trend is to compartmentalize rainscreens for better pressure equalization performance and rain penetration control. Advisable that air barriers be designed for pressure equalized construction since compartmentalization of cavities a may be adapted at a later date during retrofit work.

Comparison of Ultimate Wind Pressures for Air Barrier Design recommended by Morrison Hershfield with previous recommendations

The C.M.H.C. report "The Development of Test Procedures and Methods to Evaluate Air Barrier Membranes for Masonry Walls" [5], written by Ortech, made recommendations on NBC derived ultimate suction loads acting on air barriers.

Our recommended air pressure loads are approximately 30% higher than those of this previous report. The different assumptions are tabled below.

$$P = qC_e \, C_g \, C_p \times 1.5$$

The Ortech and Morrison Hershfield reports differ in the reference hourly wind pressure and pressure coefficients used.

q	=	0.34 KPa	Ortech report (mean value of q 1/10)
	=	0.65	Morrison Hershfield report (value exceeded at few inhabited locations in Canada)
C_p	=	1.5	Ortech report
	=	1.0	Morrison Hershfield report (vector sum of - 0.7 external suction and +0.3 interior pressure for building with uniformly distributed openings)
C_g	=	2.5	Ortech and Morrison Hershfield reports

The external C_p C_g value used by Morrison Hershfield's report is 1.75 which is in agreement with Fig. B-8 of Commentary B of the Supplement to the National Building Code of Canada 1990.

The important point is that there is a consensus that air barriers should be designed for wind pressure loads and the value of these recommended ultimate loads are significant (e.g. 20 storey building Ortech -2600 Pa, Morrison Hershfield -3400 Pa).

Design Loads for Stack Effect and Mechanical Pressurization

Upper bound for combined air pressure load due to stack effect and mechanical pressurization of approximately 8.5 Pa per storey, can conservatively be used for buildings across the country (3 m storey height).

Combined Loads on Air Barriers due to Stack Effect, Mechanical Pressurization and Wind Effects

Air pressure loads due to stack effect and mechanical pressurization act for the winter months, roughly 40% of each year. The likelihood of peak wind loads occurring during this same period is relatively high and it is reasonable to directly add stack effect, mechanical pressurization and wind loads to determine an ultimate design.

Combining wind, stack effect and mechanically induced air pressures for the purpose of establishing total design pressure on a building envelope is not a simple matter. Wind loads on an air barrier increase with height above grade. The variation of stack effect and mechanical pressurization are not tied to height above grade, but distance from the neutral plane of the building. Stack effect pressures are affected by the total building height as well. For example, the stack effect and mechanically induced pressure acting at the first storey of a low rise building will be different than that at the first storey of a high-rise building.

Considering residential buildings which are typically less than 20 storeys in height, it can be seen that the combined effect of stack effect and mechanical pressurization may increase inward loading by up to 120 Pa and outward loading by up to 170 Pa. Maximum inward loading is based on neutral plane being located as high as 70% of the building height. Maximum outward loading is based on mechanical pressurization depressing the neutral plane to the base of the building.

The following chart for "ultimate" or "factored" code-derived loads due to wind, stack effect and mechanical pressurization would be generally applicable across the country.

Ht. of Air Barrier Above Ground	Max. Inward Load	Max Outward Load
0 to 6 m	2500 Pa	2400 Pa
6 to 12 m	2800 Pa	2600 Pa
12 to 2 cm	3100 Pa	2800 Pa
20 to 30 m	3400 Pa	3100 Pa
30 to 44 m	3600 Pa	3300 Pa
44 to 64 m	3900 Pa	3600 Pa

Cyclic Loads Acting on Air Barriers Due to Wind

Some building materials will fail at lower value of cyclic loading than the load which causes failure when applied a single time. This phenomenon is known a fatigue.

Fatigue of structures due to wind loading has not generally been a concern except for structures susceptible to wind induced vibration. However, the British Research Establishment has suggested that wall cladding can be tested in a laboratory to simulate the repeated wind loadings which will occur over a 50 year design life [6].

The fatigue testing program suggested by BRE involves 6401 cycles of load (1 at 100%, 5 at 90%, 25 at 80%, 70 @ 70%, 300 @ 60%, 1200 @ 50% and 4800 at 40% of design wind pressure). Readers should consult the BRE publications for definition of their design wind pressure and basis for their recommendations. Fatigue testing of air barrier materials of systems is expensive and unwarranted unless a material known to perform questionably when subjected to cyclic loading.

However, it would be worthwhile determining whether cyclic loading does have adverse affects on load carrying capacity of materials being used to provide air-tightness planes. To date, for example, no tests have been conducted on effect of cyclic loading on load carrying capacity of gypsum board or fastener for gypsum board. It is simply not known whether strength and particularly fastener pullout value may be adversely affected by cyclic loading.

For some materials such as extruded polystyrene insulation, which has been used in road and airport runway construction, it is known that cyclic loading does not degrade material strength. Designers should be cognizant that fatigue failure of building materials and connections due to wind is a distinct possibility for many wall systems. Fatigue failure of steel liners in double skin metal walls have occurred. Designers of all wall systems should be aware of the potential of fatigue failure of cladding and air barriers.

6. STRUCTURAL ADEQUACY OF AIR BARRIER MATERIALS

Structural design of an air barrier requires the following:

a) Determining loads imposed on air barrier including expected peak loads during design life, loads of long duration, and cyclic loads.

b) Calculating stresses in materials and fastening systems due to imposed loads.

c) Identifying level of stresses which can be resisted by materials and fasteners without structural failure. These stress levels may be different for short duration loads, long duration loads and cyclic loading.

d) Identifying degree of air barrier deflection that will not cause serviceability problems e.g., cracking of interior finishes, unacceptable movement of insulation away from adjacent plane, and inability to pressure-equalize rainscreen wall cavity.

The previous chapter provided values for design air pressure loads (peak loads, long - duration loads and cyclic loads) which are generally applicable across the country and are based in part on the NBC wind loading provisions for cladding.

This chapter will present information currently available regarding items b, c, and d.

A limited amount of test information is available regarding load carrying capacity of common air barrier materials and systems. Few of the standards governing building materials used as air barriers, have explicit structural requirements.

The types of materials/systems reviewed here include the following:

- gypsum board
- rigid insulation
- polyethylene
- membranes
- exterior insulation finishing systems

Gypsum Board

Gypsum board is a building product with flexural strength that is used to span between wood or steel studs, typically at 400 mm o.c.

The stresses in a board material spanning between studs and the forces in fasteners connecting the board to the studs, will depend on over how many stud spaces the boards spans continuously.

Typically, regardless of how many spans are involved, the maximum bending moment in the board will be less than or equal to (pressure) (stud spacing) $^2/8$. The maximum reaction at a stud will be less than or equal to 1.25 x (pressure) (stud spacing). Charts to follow are based on these values of bending moment and reactions.

Gypsum board has different flexural strengths in two directions. The fibres in the paper facing on gypsum board run parallel to the long direction of standard 1.2 m x 2.4 m sheets. The flexural strength of the board is approximately 2.5 times stronger when bending in the lengthwise direction compared to the crosswise direction. Gypsum Board Standards specify the average breaking strengths required for various thicknesses of gypsum board. The required breaking strengths are different for the two directions of a board.

Structural design requires knowledge of the variability of material performance. The CSA Standard A 82.27 - M1977 "Gypsum Board" is typical of many building product standards in that it contains "structural" requirements only in the form of average flexural strength and fastener pullout resistance.

Representatives of gypsum board manufacturers have commented that the structural properties of gypsum board are quite variable and that specific information is unavailable on variability of flexural strength or fastener pullout resistance.

One manufacturer of an exterior insulation finishing system has published fastener spacings for their gypsum board substrate. Their recommendations incorporate a factor of safety of two against average nailhead pullout resistance of the gypsum board standards.

The following chart similarly incorporates a strength reduction factor of 0.5 to average flexural and nailhead pullout strengths. The chart provides information on use of gypsum board as an air barrier or structural support for an air barrier.

			STUD SPACING					
			300 mm		400 mm		600 mm	
HEIGHT OF GYPSUM BOARD ABOVE GRADE	**INWARD LOAD MAXIMUM Pa**	**OUTWARD LOAD MAXIMUM Pa**	**Maximum Factored Bending Moment**	**Factored Connection Forces**	**Maximum Factored Bending Moment**	**Factored Connection Forces**	**Maximum Factored Bending Moment**	**Factored Connection Forces**
0 to 6	2500	2400	28 Nm/m	900 N/m	50 Nm/m	1200 N/m	113 Nm/m *	1800 N/m
6 to 12	2800	2600	32 Nm/m	975 N/m	56 Nm/m	1300 N/m	126 Nm/m *	1950 N/m
12 to 20	3100	2800	35 Nm/m	960 N/m	62 Nm/m *	1400 N/m	140 Nm/m *	2100 N/m
20 to 30 m	3400	3100	38 Nm/m	1030 N/m	68 Nm/m *	1530 Nm/	153 Nm/m *	2325 N/m
30 to 44	3600	3300	41 Nm/m	1100 N/m	72 Nm/m *	1650 N/m	162 Nm/m *	2475 N/m
44 to 64	3900	3600	44 Nm/m	1180 N/m	78 Nm/m *	1800 N/m	176 Nm/m **	2700 N/m

Board Type Air Barrier
Factored Connection Force for Board Type Air Barrier
Note: Unless noted otherwise $^1/_2$" thick gypsum board oriented vertically or horizontally is adequate.

* denotes $^1/_2$" thick gypsum board required - installed with lengthwise direction of board horizontal

** denotes $^5/_8$" thick gypsum board required - installed with lengthwise direction of board horizontal

The previous chart and screw spacing chart below are based on using $^1/_2$ of average test data as lower board values. This is consistent with recommendations of some gypsum board end users e.g. some (EIFS) systems.

For gypsum board fasteners:
Factored Fastener Pull-out Value for 1/2" Gypsum Board = 325N x .5 = 162 N
Factored Fastener Pull-out value for 5/8" Gypsum Board = 365N x .5 = 182 N

For gypsum board installed horizontally:
Factored Flexural Resistance 1/2" Gypsum Board = 162 Nm/m
Factored Flexural Resistance 5/8" Gypsum Board = 220 Nm/m

For gypsum board installed vertically:
Factored Flexural Resistance 1/2" Gypsum Board = 59 Nm/m
Factored Flexural Resistance 5/8" Gypsum Board = 72 Nm/m

**Recommended Screw Spacing for Gypsum Board
Air Barrier**

	Stud Spacing		
Ht. of Gypsum Board Above Grade	**300 mm**	**400 mm**	**600 mm**
0 to 6 m	200 mm	150 mm	100 mm
6 to 12 m	150 mm	100 mm	75 mm
12 to 20 m	150 mm	100 mm	75 mm
20 to 30 m	150 mm	100 mm	75 mm
30 to 44 m	100 mm	100 mm	75 mm
30 to 44 m	100 mm	100 mm	50 mm

It is obvious that standard practice for attaching gypsum board air barrier to studs (300 m o.c. on perimeter and 400 mm o.c. for interior) does not satisfy the above screw spacing requirements which have been derived for country wide applicability. A designer should either use the spacing above or calculate screws required for the specific building in question. Advantage can be taken of fasteners of non-standard design (e.g. large head) provided test data is available.

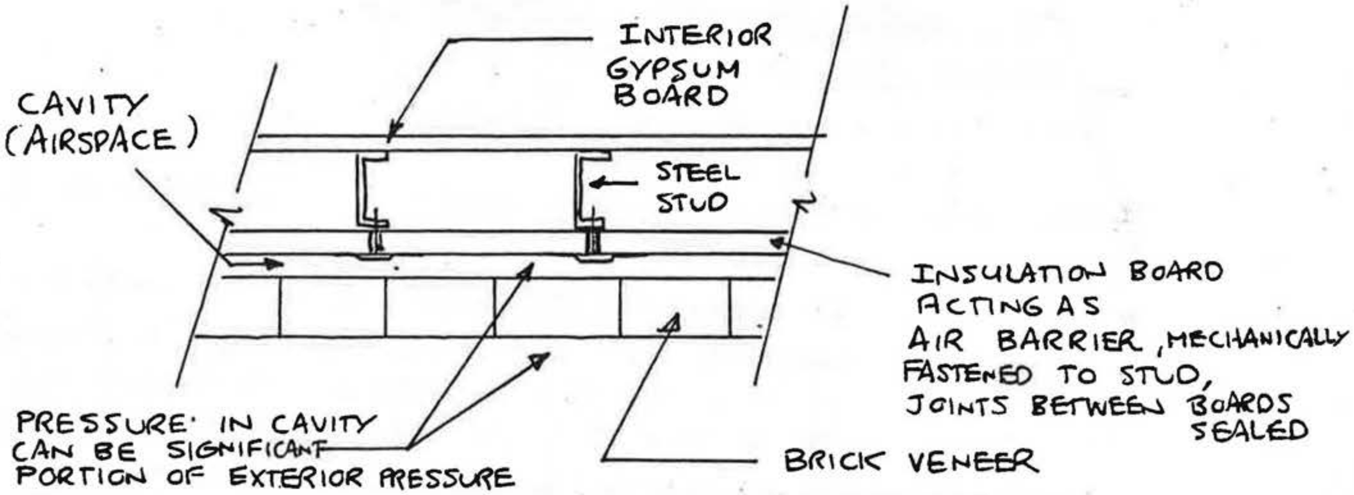
Rigid Insulation

Rigid insulation board has flexural strength. It can be used to span between wood or steel studs or can be supported between studs by a structural substrate such as gypsum board.

Certain types of rigid insulation e.g. extruded polystyrene are impermeable to air flow. They are not currently being exploited for use as air barriers due to lack of simple, durable means of sealing joints between boards. Assuming simple joint sealing techniques can be developed for rigid insulation material, the following would apply.

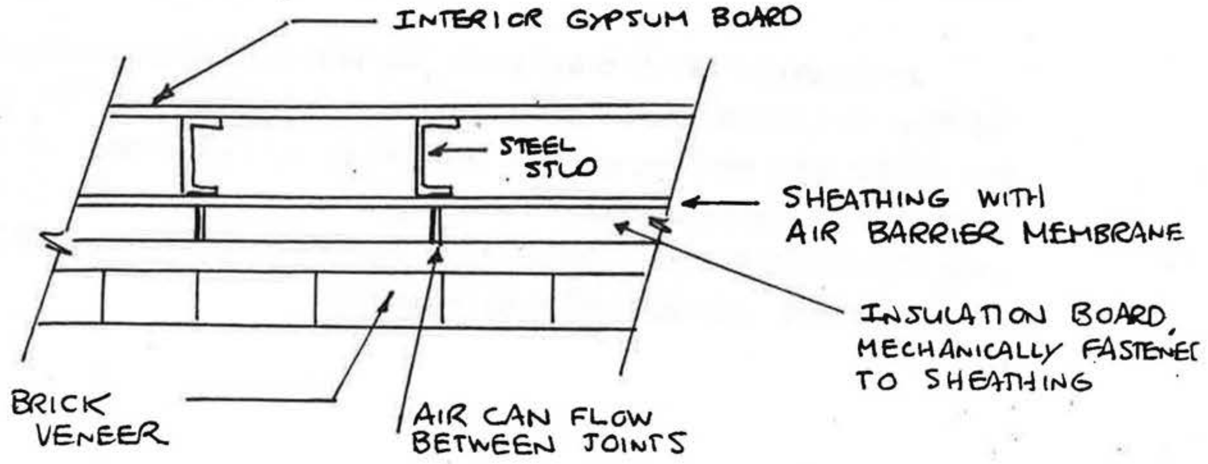
Rigid insulation material can be subjected to loads in the following situations:

1. Insulation as Air Barrier

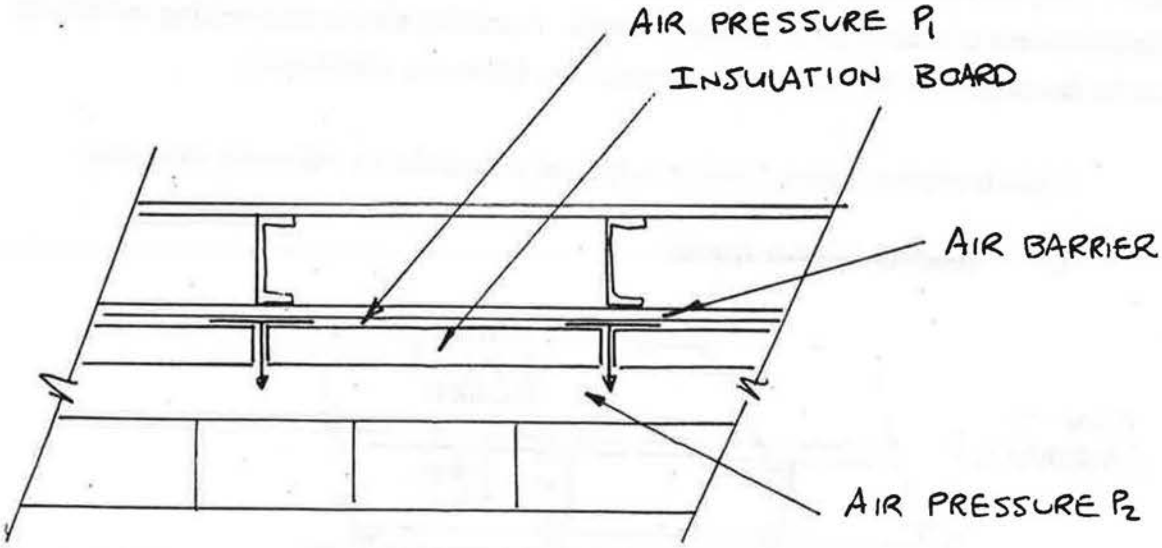


Full effects of wind, stack effect and mechanical pressurization can act in this situation.

2. Insulation relatively airtight but not the plane of most resistance to air flow - insulation not acting as air barrier



During negative wind gusting, an unbalanced load equal to the gust component of the exterior wind pressure can be acting on insulation and its mechanical fastening system. Until air can flow from space between back of insulation board and air barrier, there will be an unbalanced load acting.



INITIALLY AIR PRESSURES P_1 AND P_2 ARE EQUAL.
NEGATIVE WIND GUST WILL CAUSE P_2 TO DECREASE.
P_1 WILL EXCEED P_2 UNTIL AIR FLOWS OUT
FROM BEHIND INSULATION BOARD AS INDICATED.

Air flows out reduces pressure behind board to equalize with new cavity pressure.

Intuitively, the less resistance there is to air flowing behind the insulation, the shorter duration unbalanced load will act on the insulation board. Resistance to air flow is a combination of resistance to air flow between joints of the board and resistance to flow behind the board itself.

Loads act on materials in wall assemblies, when installed in a way that they offer significant resistance to air movement. Unbalanced loads can act on relatively airtight planes in a wall due to the wind gusting effects discussed above. An example of this would be extruded polystyrene insulation board with tongue and groove joints. The following are conservative estimates of the unbalanced loading acting on relatively air tight planes located between the exterior cladding and the air barrier plane.

$P_{\text{unbalanced}} = q_{1/10}\, C_e\, (Cg - 1)\, Cp \times 1.5$

"ULTIMATE"
or
"FACTORED" $= (.65\ \text{KPa})\, Ce\, (1.5)(-.7) \times 1.5$

$= +1200\ \text{Pa}$
$ -1000\ \text{Pa}$

Insulation board material can be installed so that it spans between studs for both inward load and outward load, or for outward load only.

Rigid insulation can be of a number of different types each with their own structural properties as shown below.

Material	Flexural Strength min	Fasteners
Extruded polystyrene	600 KPa machine dir. 375 KPa cross dir	no available data
Rigid Polyurethane Foam Board faced both sides with aluminium foil	140 KPa min	no available data
Expanded polystyrene board	170 KPa min	no available data

Since the flexural strength requirements for the above rigid insulation material are minimum values, it is not necessary to apply as high a factor of safety to the above values as is required for gypsum board.

It is reasonable to adjust minimum flexural strengths using reduction factor of 0.8 to arrive at lower bound resistances for these materials. The following chart lists the stresses occurring in board of varying thickness, for an applied load of +3900 Pa. This value was derived as "upper bound" or factored pressure acting on air barrier in residential buildings less than or equal to twenty storeys for country wide application.

				STUD SPACING					
				300 mm		400 mm		600 mm	
HEIGHT OF GYPSUM BOARD ABOVE GRADE m	INWARD LOAD MAXIMUM "FACTORED" Pa	OUTWARD LOAD MAXIMUM "FACTORED" Pa	t mm	Max.Flexural Stress Inward Load KPa	Max. Flexural Stress Outward Load KPa	Max.Flexural Stress Inward Load KPa	Max.Flexural Stress Outward Load KPa	Max.Flexural Stress Inward Load KPa	Max Flexural Stress Outward Load KPa
0 to 6 m	2500	2400	25	270	250	490	440	1090	990
			38	120	120	210	190	480	440
			50	70	60	120	110	270	250
6 to 12 m	2800	2600	25	300	280	540	490	1210	1100
			38	130	120	240	220	530	490
			50	80	70	130	120	300	270
12 to 20 m	3100	2800	25	330	300	590	540	1330	1010
			38	150	130	260	240	590	540
			50	80	70	150	140	330	300
20 to 30 m	3400	3100	25	360	330	640	590	1460	1330
			38	160	150	280	260	640	580
			50	90	80	160	150	360	330
30 to 44	3600	3300	25	400	360	700	640	1580	1440
			38	170	150	310	280	690	630
			50	90	90	170	150	390	360
44 to 64	3900	3600	25	430	390	750	625	1670	1520
			38	190	170	330	278	780	710
			50	110	100	190	157	420	380

Required Flexural Strengths of
Rigid Insulation Board for
Air Barrier Use

Insulation Board Material	Min Flexural Strength	Factored Flexural 20 storeys	Required Thickness of Rigid Insulation Buildings less than 20 storeys Insulation Acting as Air Barrier		
			Stud Spacing		
			300 mm	400 mm	600 mm
Polyurethane Foam Board	140 KPa	110 KPa	50 mm	100 mm	200 mm
Expanded Polystyrene Board	170 KPa	140 KPa	50 mm	75 mm	175 mm
Extruded Polystyrene machine direction	600 KPa	480 KPa	25 mm	38 mm	50 mm
Extruded Polystyrene transverse direction	375 KPa	300KPa	38 mm	50 mm	125 mm

Rigid insulation which has been installed to act as an air barrier must be capable of resisting an ultimate pressure of +3900, -3600 Pa for use across Canada in buildings of twenty storeys or less. Positive pressure is pressure directed inwards into a building.

				STUD SPACING					
				300 mm		400 mm		600 mm	
HEIGHT OF GYPSUM BOARD ABOVE GRADE	INWARD LOAD MAXIMUM "FACTORED"	OUTWARD LOAD MAXIMUM "FACTORED"	t mm	Max.Flexural Stress Inward Load KPa	Max. Flexural Stress Outward Load KPa	Max.Flexural Stress Inward Load KPa	Max.Flexural Stress Outward Load KPa	Max.Flexural Stress Inward Load KPa	Max Flexural Stress Outward Load KPa
0 to 6 m	1080 Pa	900	25	117	97	205	170	468	388
			38	51	43	90	76	204	172
			50	29	24	51	42	116	96
6 to 12 m	1200	1000	25	130	108	228	190	520	432
			38	57	48	100	85	228	192
			50	32	27	56	48	128	108
12 to 20 m	1320	1100	25	143	119	252	210	572	476
			38	63	53	110	93	252	212
			50	35	30	62	53	140	120
20 to 30 m	1440	1200	25	156	130	275	228	624	520
			38	68	58	120	102	272	232
			50	38	32	69	56	152	128
30 to 44	1560	1300	25	169	140	298	246	676	560
			38	74	62	130	109	296	248
			50	41	35	72	62	164	140
44 to 64	1680	1400	25	182	151	320	265	728	604
			38	80	68	140	120	320	272
			50	45	38	79	67	180	152

Required Flexural Strengths of Rigid Insulation Board for
Installation Relatively Air Tight and Insulation Affected by Gust Component Exterior Wind.

Insulation Board Material	Min Flexural Strength	Factored Flexural Strength	Required Thickness of Rigid Insulation Buildings less than 20 storeys Insulation Relatively Airtight but not Air Barrier		
			Stud Spacing		
			300 mm	400 mm	600 mm
Polyurethane Foam Board	140 KPa	110 KPa	38 mm	50 mm	75 mm
Expanded Polystyrene Board	170 KPa	140 KPa	38 mm	38 mm	50 mm
Extruded Polystyrene machine direction	600 KPa	480 KPa	25 mm	25 mm	38 mm
Extruded Polystyrene transverse direction	375 KPa	300KPa	25 mm	38 mm	50 mm

Rigid insulation which is not acting as air barrier can still be subjected to gust component of exterior wind pressures which result in an ultimate pressure of +1680 Pa, -1400 Pa for a twenty storey building.

Polyethylene

Polyethylene sheet material is routinely installed in buildings to act as a vapour barrier. Polyethylene is a material which is relatively impermeable to air leakage. Consequently, polyethylene has been relied on in many designs to provide an air barrier function.

Polyethylene sheet is a material which has no bending strength. Polyethylene sheet cannot support compressive stresses and will deform to shape required to resist the applied loads by tensile membrane stresses only. This type of structure is termed a *tensile* structure.

Tensile structure air barriers have the following disadvantages:

1. A membrane material must either be installed with sufficient slack, or significantly deform under load in order that the applied air pressure may be resisted by tensile membrane stresses only.
2. Insulation is commonly placed tight to one side of an air barrier. If the air barrier has to deform to resist loads, then the insulation material may become displaced by the air barrier.
3. If the air barrier has to deform to resist loads, there is a chance that the air barrier may contact protruding nails etc. and be punctured.
4. If pressure equalization is sought, one cannot allow the volume of the cavity to change with cavity pressure. Tensile structure air barrier may deflect too much to permit pressure equalization.
5. Joints in the air barrier and connections of the air barrier to the supporting structure must resist significant plane tensile stresses. Full strength joints are required between sheets and tearing of sheets at connections to the structure must be protected against.

It is worthwhile discussing a specific example for illustration purposes. Let us consider a sheet of 6 mil (0.150 mm thick) polyethylene sheet spanning between studs spaced at 400 mm o.c. Polyethylene film used in building construction is typically low density polyethylene, has a minimum tensile strength in the order of 12 MPa in the machine direction and 8 MPa in the cross direction. For calculation purposes, let us take .8 x (8 MPa) = 6.4 MPa as the "factored" or "ultimate" tensile strength of the film.

We can then calculate the applied pressure the polyethylene can resist without exceeding its factored tensile resistance, or an allowable deflection. Let us suppose that we will permit 12 mm of central deflection of polyethylene between studs under maximum wind effects.

The maximum air pressure loads that can be resisted without deflection exceeding 12 mm, and without tensile stress exceeding 6.4 MPa can be calculated as follows :

$P = H \times 8\, h/L^2$ catenary formula

where P = air pressure

H = tensile stress in membrane

= 6.4 MPa max.

h = central deflection of membrane

= 12 mm max.

L = span of membrane

= 400 mm

$$P = \frac{(6.4 N/m^2) \times 0.150\ mm\ (8)(12\ mm)}{(400\ mm)^2}$$

= 600 Pa

If 6 mil polyethylene spanning in the machine direction is permitted to be stressed up to its tensile strength of 12 MPa, then the sheet can resist approximately 1100 Pa applied pressure without exceeding 12 mm central deflection. If 4 mil polyethylene sheet spanning in the machine direction is permitted to be stressed up to its tensile strength, then the sheet can resist approximately 750 Pa without exceeding the same 12 mm central deflection.

For the much higher levels of applied pressure that will act on air barriers during a building's life (as high as +3900, -3600 Pa for use with building less than 20 storeys located anywhere in Canada) low density polyethylene sheet in thicknesses currently being used is not a suitable air barrier material.

The National Research Council of Canada has conducted air leakage tests on polyethylene membrane installed in wood framed walls. In these tests, air pressure differentials as high a 865 Pa were applied to 4 mil polyethylene spanning 400 mm between studs [3]. It appears from photos in the report that the deflection for this load was in excess of 12 mm as would be predicted from structural calculations.

Polyethylene sheet currently being used in construction 4 mil or 6 mil low density polyethylene sheet is not suitable for use as an unsupported air barrier because it cannot resist significant air pressure without unacceptably large deformation. Construction practice has sensibly been to avoid joining sheets of polyethylene midway between studs. Instead, connections are joined only to the studs and polyethylene sheets are overlapped to cover one stud space. Critical to the success of this type of tensile structure to resist loads is the avoidance of connection failure by tearing of the polyethylene sheet. However, polyethylene is available in a wide range of thicknesses and is also available in medium and high densities which have significantly higher strengths. The following are indicative of the range of tensile strengths available in polyethylene films.

Material	**Tensile Strength MPa**
Low density polyethylene	12 MPa - 18 MPa
Medium density polyethylene	14 MPa - 24 MPa
High density polyethylene	21 MPa - 68 MPa

Critical to the successful use of unsupported polyethylene as an air barrier will be availability of thicker and or stronger which can be joined and fastened to studs in a reliable manner.

Low density polyethylene sheet (4 or 6 mil) currently being used in building constructions has serious limitations as an unsupported air barrier. One approach to overcoming its limitations for air barrier use is to sandwich the polyethylene sheet between two rigid materials, such as two sheets of fibreboard. Nevertheless, building envelopes in many situations do require that they have areas of the air barrier which can resist tensile stresses only. A material which resists only tensile stresses can bridge between the main building structure and the building envelope system with no danger of transmitting to the building envelope the effects of column shortening, slab deflections, differential settlement of building.

Membranes

Air barrier membranes are typically adhered thermo-fused, troweled on, spray applied or mechanically fastened to an underlying structural substrate. Earlier it was recommended that air barriers to be installed at any height on residential structures less than 20 storeys (64 m), should be capable of resisting an ultimate outward (suction) pressure of 3400 Pa.

The C.M.H.C. sponsored study by Ortech [5] on air barrier membranes for masonry walls tested thirty eight air barrier membrane on masonry walls, for 10 second application of -3000 Pa, and 1 hour application of -1000 Pa applied pressure. The 10 second tests showed delamination in some instances.

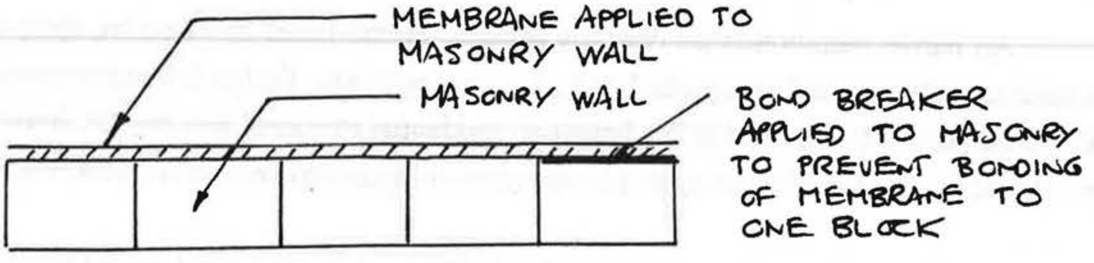
Structurally it is important to know what size of delamination can occur, without sacrificing the ability of the membrane to withstand the ultimate design pressures expected to act upon it during the life of the building.

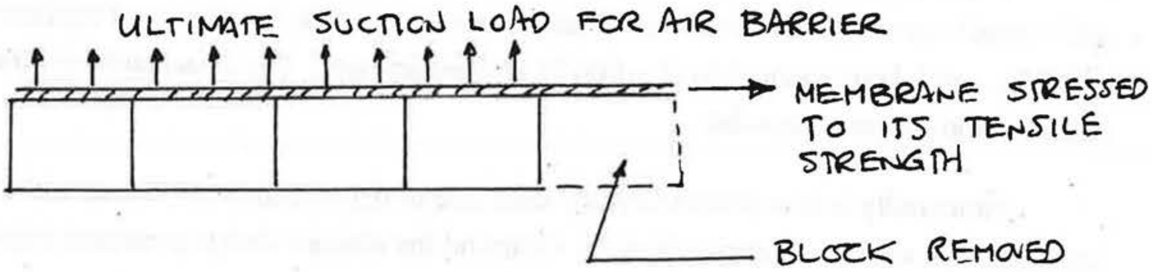
Membranes can transfer applied air pressures across small gaps by a combination of bending and membrane action. For larger areas such as delamination, air pressure loads will be resisted by membrane action only. There are two aspects limiting how large a delamination can be.

1. The larger a delamination is, the higher the tensile stress that will develop in the membrane for a given "slackness" of delamination. The worst case is a taut delaminated membrane because it will need to develop much higher tensile stress than a slack delamination to resist air pressure loads.

2. The bonding of the perimeter of a delaminated area will experience much higher forces tending to pull the membrane off the substrate in a tensile mode than the fully bonded sections of membrane. Additionally, the tensile stress which develops in the delaminated membrane requires shear forces to be transmitted by bond around the perimeter.

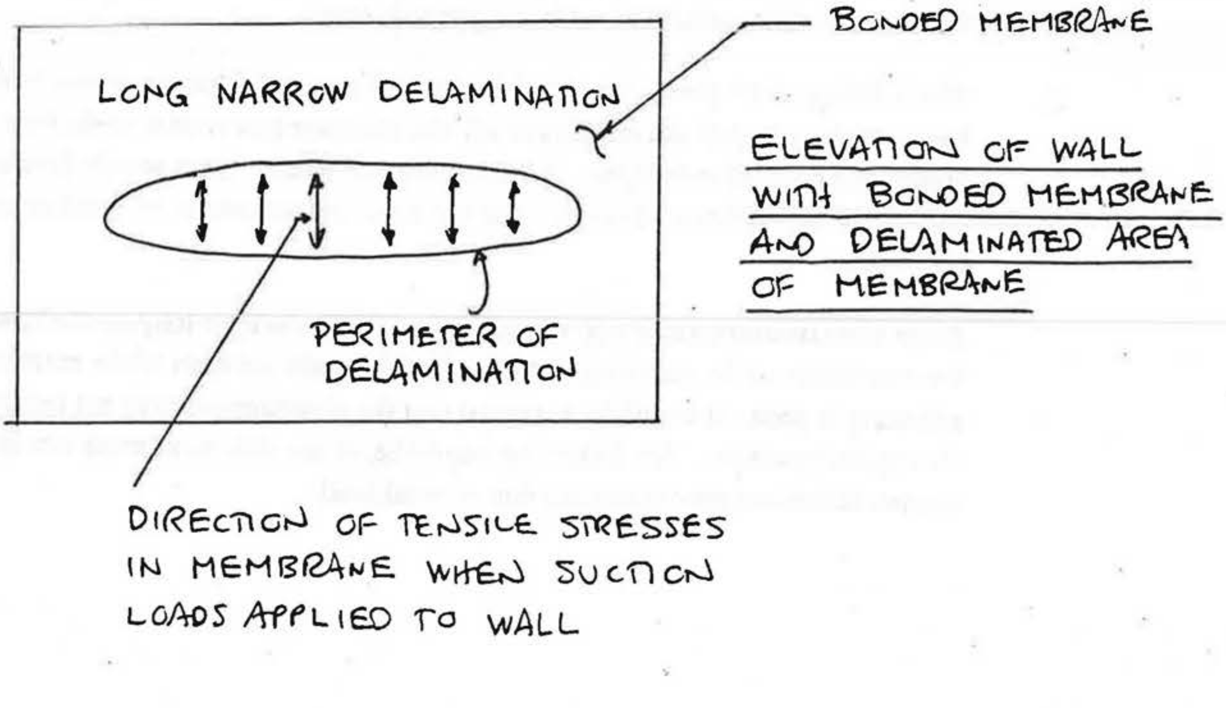
   Since most delaminations will not have significant slack, as long as the bonding of the membrane to the substrate can transfer the tensile strength of the membrane to the substrate in shear, it would be expected that the delamination will not enlarge due to the applied pressure. The following would be as possible membrane test to guard against delaminations increasing due to wind load.



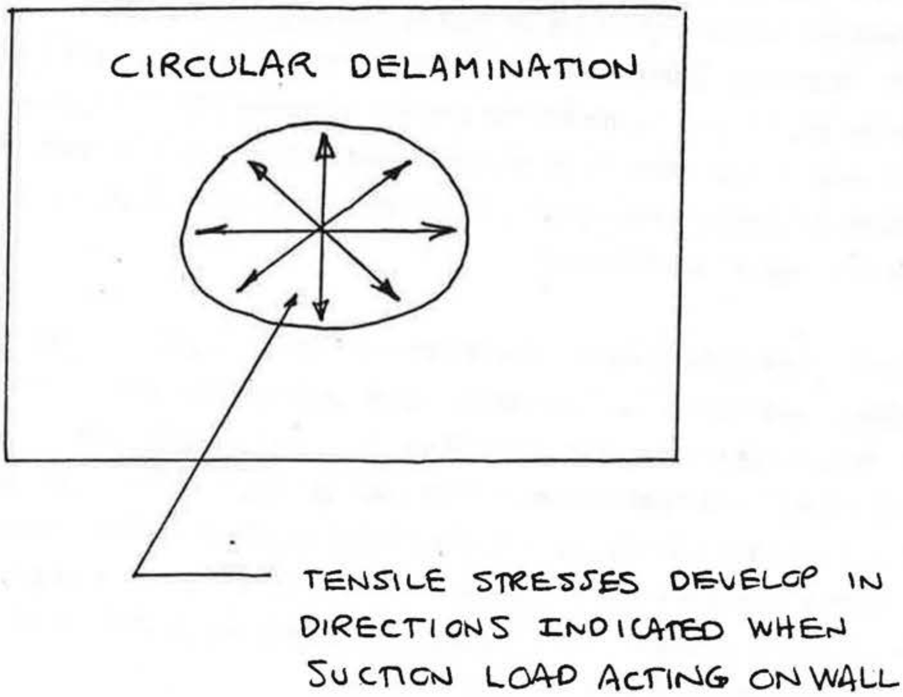


If the membrane can adhere to the substrate under the ultimate design suction and concurrent shear loading shown above, then the limitation delaminations need only be limited to a size so as not to exceed the tensile strength of the membrane material.

The shape of a delamination will determine how loads are transferred to surrounding bonded membrane. An unbonded strip of membrane will span one way and act as a catenary.



A circular shape delamination will resist applied pressure by spanning to its entire perimeter. Each delamination will resist applied loads as required by the shape of the delamination.



TENSILE STRESSES DEVELOP IN DIRECTIONS INDICATED WHEN SUCTION LOAD ACTING ON WALL

It is possible but beyond the scope of this report to determine allowable size delaminations of different shapes for given membrane materials.

Exterior Insulation Finishing Systems

Exterior Insulation Finishing Systems are proprietary cladding systems consisting of exterior finish adhered to insulation which may be mechanically or adhesively fastened to an underlying sheathing substrate such as gypsum board, plywood or cement board spanning between studs. The insulation may also be adhered or mechanically fastened directly to a masonry or concrete wall. In some cases, the insulation is used to span between studs without a sheathing substrate.

Typically the air barrier is provided at the exterior finish and at a caulking seal between panels. The load path for air pressure loads is straight forward.

Manufacturers literature should be reviewed to verify that structural test results have been conducted for their systems. Some proprietary systems, have been tested successfully to negative static pressures of -6000 Pa with no cracking, delamination or other damage. Non-standard fasteners and spacing were used to connect gypsum board substrate to the structure for these tests. This does not invalidate the test results for the EIF system but should caution designers to ensure that the structure supporting the EIF system must be engineered, as is recommended by the manufacturers. One needs to be careful to verify that your application duplicates exactly the construction of the test specimen, and that any special fastener details required are followed.

The practice of performing structural tests to only 150% of a code derived specified design pressure is questionable. This represents the factored wind pressure which is an upper bound on the pressure to be exerted on a component during its design life. In order to account for variability in materials and construction, one has to test to in excess of this pressure in order to establish the general structural adequacy of a system and not just one test sample. For example, some manufacturers use a factor of safety of two for gypsum board fasteners. If a test is conducted to 1.5 x specified design pressure, than the test does not validate the connection of the gypsum board sheathing.

7. CODE BASED AND ALTERNATIVE APPROACHES TO WIND LOADING

In this chapter we wish to consider an example calculation of "ultimate" wind loads on an air barrier based on:

- NBC cladding loads applicable across the country
- NBC cladding loads for specific locations
- alternative approach based on given design life and given probability of exceeding ultimate design load

Using NBC Cladding Loads Applicable Across Country

$CP_{INWARDS}$ = 1.1 (summation of internal and external pressures)
$CP_{OUTWARDS}$ = 1.0 (summation of internal and external pressures)

Ce = 1.1 (for 20 m elevation above grade)
Cg = 2.5
$q_{1/10}$ = .65 KPa
$P_{INWARDS}$ = $(q_{1/10})(Ce)(Cg)(1.1) \times 1.5$ = 2.95 KPa
"ULTIMATE/FACTORED"
$P_{OUTWARDS}$ = $(q_{1/10})(Ce)(Cg)(1.0) \times 1.5$ = 2.68 KPa
"ULTIMATE/FACTORED"

Using NBC Cladding Loads For Specific Site - e.g. Ottawa, Ontario - 20 m above grade

Ce, Cg, Cp coefficients as above
$q_{1/10}$ = .30 KPa
$P_{INWARDS}$ = 1.36 KPa
"ULTIMATE/FACTORED"
$P_{OUTWARDS}$ = 1.23 KPa
"ULTIMATE/FACTORED"

Using Alternative Approach Based on Design Life and Probabilities

For a given design life of an air barrier and desired probability of exceedance during the design life, one can calculate the "return" period required for wind.

Let p = probability of hourly average wind speed not being exceeded in any given year

e.g. p = .9 for 10 year return wind

If design life is 50 years and want only 5% chance of exceedance then the following calculation shows that the 1000 year return wind must be used.

$1-P^{50} = .05$
➡ $p = .999$
➡ 1000 year return wind

Design Life 10 years	Probability of Exceedance During Design Life	Return Period Required
10	.05	200
25	.05	500
50	.05	1000
50	.10	500

For Ottawa, Ontario

$q_{1/10}$ = .30 KPa V_{10} = 48.2086 mph

$q_{1/30}$ = .37 KPa V_{30} = 53.53499 mph

$q_{1/100}$ = .46 KPa V_{100} = 59.69195 mph

The following equations may be used to calculate wind velocities of different return periods for sites in Canada. The first step is to calculate the parameter called (${}^1/_a$) for the site. This parameter can be calculated using the wind velocities corresponding to the stagnation pressures for q ${}^1/_{100}$ and q ${}^1/_{30}$. Once the parameter (${}^1/_a$) is known for the site, the wind velocity for a given return period can be calculated as follows:

$V_n = V_{30} - {}^1/_a \ln (\ln {}^{(1\ 1/30)}/\ln (1 - {}^1/_n)$

The stagnation pressure for V_n is denoted q ${}^1/_n$ and is calculated as follows:

q ${}^1/_n = (V_n)^2$ (.00012919) where

V_n is in mph and q ${}^1/_n$ is in KPa

For Ottawa

$${}^1/_a = \frac{V_{100} - V_{30}}{\ln (\ln(1-{}^1/_{30})/\ln(1-{}^1/_{100}))}$$

$$= \frac{59.69195-53.53499}{\ln (-.0339015)/(0.0100503))}$$

$$= \frac{6.1565}{1.17179} = 5.254$$

Calculate stagnation pressure for 200 year return period wind in Ottawa

e.g. V_{200} = 53.534991 - 5.254 $\ln(\ln(1-{}^1/_{30})/\ln(1-{}^1/_{200}))$

= 53.53499 + 5.254 ln (-.0339015/-.0050125)

= 63.6 mph

$q_{1/200}$ = .52 KPa

Calculate stagnation pressure for 500 year return period wind in Ottawa

e.g. V_{500} = 53.53499 + 5.254 ln(-.0339015/-.002002)

= 68.4 mph

$q_{1/500}$ = .60 KPa

Calculate stagnation pressure for 1000 year return period wind in Ottawa

e.g. V_{1000} = 53.53499 + 5.254 ln(-.0339015/-.00100)

= 72 mph

$q_{1/1000}$ = .67 KPa

8. CONCLUSIONS AND RECOMMENDATIONS

- Air barriers are subjected to pressure arising from stack effect, mechanical pressurization of building interiors, and exterior and interior pressures due to wind effects.

- Air barriers must remain effective during building life to help maintain a controllable indoor environment, and prevent premature deterioration of the building envelope.

- Building materials including air barriers do not have to be located on the exterior skin of the building envelope to be subjected to exterior wind pressures.

- It is known from field measurement and laboratory testing that cavity pressure in a rainscreen wall will equalize with exterior gust wind pressures, when lateral air flow within a cavity is prevented.

- At the present time, it is not possible to establish the percentage of exterior wind pressures which will act on an air barrier in a rainscreen wall design when air can flow within the cavity itself. Considerable analytical and experimental work would be required to develop a model which could predict response of non-compartmentalized cavity walls to wind effects.

- Air barriers should be designed for summation of exterior and interior wind pressures including gusting, and pressures due to stack effect and mechanical pressurization.

- At the present time, it is logical to use the National Building Code of Canada provisions for cladding to assess structural adequacy of air barriers. The first priority must be to establish a set of conservative structural guidelines which are applicable across the country. Until air barriers are designed for structural loads, we can expect premature structural failure of air barriers to be a common occurrence.

- At the present time air barriers should be designed as a minimum for the wind loads for cladding from the NBC. However, as illustrated in Chapter 7 the use of 1.5 x q $^{1}/_{10}$ for ultimate load does not guarantee a small probability of exceedance for the design lives typically sought for building construction e.g. 50 years. Excessive cladding failures of traditional materials (concrete, brick, steel, aluminum) have not occurred with cladding designs using the NBC code and q $^{1}/_{10}$ reference wind pressures. Nevertheless, for the reasons indicated in Chapter 7, it is prudent to seriously consider requiring that air barrier materials be capable of withstanding factored loads based on q $^{1}/_{30}$.

- Ultimate or factored pressures have been derived in this report which are generally applicable in Canada for design/evaluation of air barriers in residential construction of less than or equal to twenty storeys (64 m). These "ultimate" or "factored" pressures are based on National Building Code provisions for wind loading of cladding. This information is contained in Chapter 5 of the report.

- Structural design practice involves determining:

  a) the extreme load during a building life which has an acceptably low probability of exceedance.

  b) the load which the structure can resist with an acceptably low probability of failure.

  Knowing both the loads and the material resistance, a structural design can be established which has an acceptably low probability of loads exceeding resistance (i.e. structural failure). Chapter 7 illustrated the type of probability based calculations of wind loading which can be done.

- The loads (particularly wind loads) which are identified in building codes are not presented in a format enabling a designer to identify the appropriate level of loading for a given building life and given probability of exceedance. This has been done deliberately to ensure uniformity between code-designed buildings. However, there are many instances when it would be worthwhile to have the option of using other than the built-in assumptions of the code wind-loading provisions. For example, it may be reasonable to design air barriers utilizing interior gypsum board for higher probabilities of failure than an air barrier in which structural failure due to severe wind loading will go undetected.

- Value of sustained pressures have been proposed as appropriate for investigations of creep effects due to sustained loads on air barriers. This information is contained in Chapter 5 of the report.

- Should fatigue loading concern for the air barrier materials being used, there is guidance available on cyclic loading to "duplicate" the fatigue effects of wind loading. This information is contained in Chapter 5.

- Materials other than air barriers are subjected to wind effects within wall assemblies. Wind effects can cause undetected structural failure of insulation within the cavity of a wall. Loads have been recommended for structurally design/evaluation of relatively airtight (but not air barrier planes) materials located within wall assemblies. See Chapter 5 for details.

- The adequacy of current construction practice of air barriers has been discussed for the following materials: gypsum board, rigid insulation, polyethylene, membrane, and exterior insulation finishing systems. In addition, guidance has been given on structural requirements for insulation materials which are relatively airtight (but not the air barrier plane). Advice has been given on the factors affecting the allowable size of delaminations of membrane to structural substrate. Please refer to Chapter 5 for this information.

- There is a severe lack of knowledge regarding the structural properties of air barrier material and fasteners. Without knowledge of the variability in these structural properties, it is not possible to rationally establish appropriate lower bound strengths for the variety of building materials being used as air barriers. The practice of testing a wall construction to 1.5 x "ultimate" or "factored" code-based wind load, is only appropriate for constructions where the test sample is very representative of the actual construction. For manufactured building components constructed of building material with strict quality control i.e. (steel, aluminium) this is reasonable.

  When considering constructions of building materials which have higher variability than steel or aluminium, it is not reasonable to test to only the factored wind pressure, since the test sample may not be representative of the actual construction.

- **Although there is information which should be developed to aid structural design of air barriers, this does not present air barriers from being structurally designed at the present time.**

- **Information regarding structural strengths of air barrier materials and their fasteners will be forthcoming from manufacturers when requested by the design community.**

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