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Air Barrier Systems for Walls of Low-Rise Buildings: Performance and Assessment

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1. FOCUS OF THIS PUBLICATION

1.1 Context

Air movement is the dominant factor in the transport of moisture through building envelope assemblies. It is also an important component of heat transfer. Many problems concerning building envelope deterioration can be attributed to inadequate or failed air barriers.

The National Building Code of Canada (NBC) contains requirements for air barrier systems that reflect industry's knowledge, experience and practice. Important changes in the air barrier system requirements have been incorporated into the 1995 NBC to correspond to the evolution of thought since the previous edition. The new National Energy Code for Buildings references the NBC air barrier system requirements, and a method for the evaluation of air barrier systems for walls of low-rise buildings has been developed by the Canadian Construction Materials Centre (CCMC).

1.2 Purpose

This publication is intended to help designers and building officials to understand the fundamental performance requirements of air barrier systems, related code requirements and the testing and assessment of suitable air barrier systems. It will also help manufacturers of air barrier systems to develop materials and systems suitable for use. In particular, this publication:

- Reviews the requirements for air barrier systems provided in Part 5 and Part 9 of the 1995 NBC and the intent of these requirements.
- Explains the contents, intent and significance of CCMC's Technical Guide for *Air Barrier Systems for Exterior Walls of Low-Rise Buildings* and its application in the design and construction of wall systems that comply with NBC requirements (CCMC guides are not intended for general distribution).
- Explains how the new requirements and new knowledge regarding the performance of air barrier systems for walls will likely affect the design of different wall types in low-rise, normal-humidity (up to 35% RH) buildings.
- Provides advice on how the information presented can be extended to high-rise buildings, high-humidity buildings and other building envelope assemblies.

1.3 Audience

The targeted readership of this publication is:

- designers and specifiers (architects, engineers, technologists and building science professionals);
- construction supervisors and managers responsible for establishing construction methods and quality control;
- manufacturers of air barrier systems or materials forming part of air barrier systems; and building officials needing to understand the intent of the NBC and to determine compliance.

2. THE AIR BARRIER SYSTEM

The air barrier system, as defined in the 1995 NBC, is *"The assembly installed to provide a continuous barrier to the movement of air."*

2.1 Fundamental Requirements of Air Barrier Systems

Over 30 years ago, Neil Hutcheon[1] listed the principal requirements of a wall. The air barrier system is fundamental to the requirement concerning the control of air, heat and water vapour flows. It also plays an important role in the control of rain penetration and external noise transmission.

To meet these requirements, the air barrier system of a wall must be:

- constructed of materials that are adequately airtight;
- continuous through the building envelope;
- strong enough to resist the air pressure loads imposed on it, transfer these loads to the building structure and have enough rigidity or support so that deflection under load is accommodated in the specific wall design;
- durable enough to provide the necessary performance in the service environment anticipated;
- buildable.

2.2 Evolving Performance Requirements for Air Barrier Systems

Since the concept of an air barrier system was introduced, much research has focused on answering several fundamental questions:

- Where should it be located in the wall assembly?
- How tight must it be?
- How strong must it be?

As a corollary, the question arises, *How does the water vapour permeability of the air barrier system affect the answers to the above questions?*

The construction industry has developed numerous methods of providing better air sealing and continuity using both traditional and new materials. Some of these new materials were developed as components for air barrier systems; others have special characteristics, such as high vapour permeability, which provide greater flexibility when incorporated in air barrier system design.

The first requirement for an air barrier system was included in Part 5 of the 1960 edition of the NBC. In 1975, the requirement for a sealed vapour barrier (which was thought to act as an air barrier as well) was included in Part 9 of the NBC. In 1990, the wording of Part 9 was modified to clarify and separate the functional requirements for air barrier systems and vapour barriers. Both Part 5, *Environmental Separation*, and Part 9, *Housing and Small Buildings*, of the 1995 NBC contain new design and prescriptive requirements, respectively, for air barrier systems. What is more, the Appendix to the 1995 NBC and the Commentaries

[1] Hutcheon, N.B. *Requirements for Exterior Walls*. Canadian Building Digest (CBD) 48, Division of Building Research, National Research Council, Ottawa, 1963.

on Parts 5 and 9 provide explanatory information on these requirements.

Under the equivalency section of the NBC, alternative materials and methods of design or construction can be used where they can be shown to be equivalent on the basis of past performance, tests or evaluations. These new code requirements are not the final word. The Canadian Commission on Building and Fire Codes, which oversees the work of the technical committees that write the NBC, has indicated its intention to move the code in the direction of objective-based requirements. This will facilitate development of criteria and a broader range of designs deemed to comply with the NBC and provide building designers with more flexibility.

Defining performance requirements for air barrier systems is not a simple undertaking. The hygrothermal behaviour of any building assembly is a complex interaction of heat, air and moisture flows, which are affected by all the components in the assembly, including the air barrier system. In turn, the properties and performance of the components of an assembly are affected by the hygrothermal behaviour of the assembly. Defining performance requirements for air barrier systems in a manner that can be described in a code or standard and that can be enforced in the field requires tools, methods and experience that are not always available. Assistance with both understanding the requirements and compliance with them is, however, available from NRC's Institute for Research in Construction.

3. 1995 NBC REQUIREMENTS FOR AIR BARRIER SYSTEMS

The NBC addresses issues of health and safety for the design and construction of new and rehabilitated buildings. Performance and durability requirements for air barrier systems in the NBC appropriately address health- and safety-related issues. If, for example, an air barrier system allows significant air leakage from a humidified building, deterioration of masonry supports or the masonry itself may lead to public safety hazards. Likewise, significant air leakage may result in interstitial condensation which, in turn, can lead to mold growth, a potential health hazard. On this basis, both Part 5 and Part 9 of the NBC address air leakage issues for engineered and non-engineered buildings respectively.

3.1 Air Barrier System Requirements in Part 5 of the NBC

Part 5 of the NBC, entitled *Environmental Separation*, applies to buildings other than those that fall within the scope of Part 9 (Figure 1). Many low-rise buildings fall outside the scope of Part 9 because of their size or intended use and occupancy. Designers may also wish to make use of the design flexibility afforded by designing to Part 5 requirements even with buildings that fall within the scope of Part 9. Designers of Part 9 buildings may also find Part 5 useful, because the principles described apply equally to these buildings.

Part 5 requires that all building assemblies, such as walls and roofs, that separate conditioned indoor space from outdoor environments, or dissimilar environments within a building, incorporate an air barrier system. Exceptions are permitted where it can be shown that uncontrolled air leakage does not have an adverse affect on the health or safety of the users or the intended use or operation of the building.

The requirements of Part 5 are supported and clarified in the Appendix to the NBC.

Figure 1. A high-rise building governed by Part 5 of the National Building Code

3.1.1 Air Leakage

According to Part 5, the material that provides the principal resistance to air leakage within the air barrier system is required to have an average leakage characteristic not greater than 0.02 $L/(s \bullet m^2)$ at 75 Pascals (Pa) pressure difference. (This represents the leakage rate, for example, through a 12.5-mm sheet of unpainted gypsum wallboard.) This air leakage rate at 75 Pa is not intended to represent typical leakage of the material *in situ*, since pressure differences across the building envelope are often much higher than 75 Pa. This reference pressure difference of 75 Pa is merely used to characterize a material property. The NBC allows materials of lower airtightness , i.e., leakage greater than

0.02 L/(s•m²), if it can be shown that this will not have adverse effects on the health or safety of the users of the building. The air barrier system must also be continuous across construction joints, control and expansion joints, at penetrations through an assembly, and at junctions with other assemblies.

The code committee responsible for writing Part 5 recognized that, ideally, the maximum air leakage rate of the air barrier system (including materials and joints) would be specified. This is not currently viewed as a practical approach, however, because there are relatively few published data about leakage of the air barrier system as a whole. To assist designers, the Appendix of Part 5 provides a list of recommended maximum air leakage rates suitable for most climates in Canada (Table 1 below). These air leakage rates were first suggested in IRC's Building Science Insight 86, "An Air Barrier for the Building Envelope."[2] They were based on the perceived need to provide higher levels of airtightness than required at the time by the American Architectural Manufacturers Association (AAMA). Measured tightness of assemblies performing well at the corresponding humidities has since supported the validity of the recommended rates listed in Table 1.

Table 1. Recommended maximum system air leakage rates

Warm Side (% Relative Humidity at 21°C)	Recommended Air Leakage Rate L/(s•m²) at 75 Pa
< 27	0.15
27 to 55	0.10
>55	0.05

Source: Table A-5.4.1.2, 1995 National Building Code of Canada

This system air leakage rate is the leakage through the opaque portion of the envelope and is not to be confused with the overall air leakage rate of a building as is measured by whole-building air leakage tests, such as CAN/CGSB-149.10M.[3]

3.1.2 Structural Capacity

According to Part 5, the answer to "how strong?" is that the air barrier system must be designed to resist 100% of the wind load for which the wall or roof structure is designed and that it must be supported and attached in a way that this load is transferred to the structure. Also, the structure and its air barrier system must be designed so that deflection of the air barrier system at 150% of the design wind load does not adversely affect the non-structural components of the wall or roof. No guidance is provided in the NBC, however, to indicate how this wind load should be applied when evaluating air barrier systems.

3.1.3 Durability

Part 5 requires that all materials used in the building envelope, including the air barrier system, be compatible with adjoining materials and resistant to deterioration under the loads to which they are subjected within the service environment. Where air barrier system components are covered in the scope of the referenced standards – for example, for doors and windows – the component must conform to the requirements in the standards. This typically includes material standards, sealants, and operating hardware that will affect the durability of the air barrier elements within the component. Where durability need not be considered, e.g., in temporary buildings, Part 5 does permit a relaxing of durability requirements provided it will not affect the

[2] "An Air Barrier for the Building Envelope, *Proceedings of Building Science Insight '86*. Institute for Research in Construction, National Research Council, Ottawa, NRCC 29943, 1989.

[3] CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*. Canadian General Standards Board, Ottawa, 1986.

health or safety of the users of the building. The Appendix of Part 5 discusses at length the different deterioration mechanisms that should be considered over the expected service life of the air barrier components, including structural loading, freeze/thaw, differential movement, ice lensing, corrosion, solar radiation exposure, biological attack, and intrusion by insects and rodents. Considerations of the design service life have to include the expected service conditions and the implications of premature failure, as well as the ease of access for maintenance, repair or replacement, and the cost of such repair or replacement.

3.1.4 Relationship Between Air Barrier Systems and Vapour Barriers

Many materials used in the air barrier system of walls may also have low water vapour permeance. Part 5 of the 1995 NBC recognizes that materials selected to provide the required resistance to vapour diffusion need not be limited to those traditionally recognized as vapour barriers. Part 5 does not contain prescriptive requirements for the maximum vapour permeability of materials forming the vapour barrier. Rather, it requires that the permeance of the vapour barrier material be low enough to control moisture transfer by diffusion to surfaces reaching the dew point temperature at exterior design conditions or that any condensation forming will not cause deterioration of the building or affect the health or safety of occupants.

The relationship between air barrier system performance and vapour barrier performance, therefore, often makes vapour permeance of the air barrier materials and their location in the assembly an issue in air barrier system design.

3.2 Air Barrier System Requirements in Part 9 of the NBC

Part 9 of the NBC applies to small buildings up to three stories in height and 600 m^2 in building area that do not include assembly, institutional or high-hazard industrial occupancies (Figure 2). Part 9 recognizes that professional architects and engineers may not be involved in the design of these structures. Therefore, it relies very heavily on prescriptive requirements that are based on historically established, acceptable performance. In effect, Part 9 permits limited professional design input in meeting the intent of the NBC. A building can always be designed under Parts 3, 4, 5 and 6 to make use of the added flexibility.

Subsection 9.25.3. contains the requirements dealing specifically with air barrier systems. It requires that all thermally insulated wall, ceiling and floor assemblies incorporate a continuous air barrier system to resist both infiltration and exfiltration.

3.2.1 Air Leakage

Part 9 does not currently contain quantitative requirements for maximum allowable air leakage of either an air barrier system or the materials used to form it. The wording requires that the air barrier system provide "an effective barrier to air exfiltration under differential air pressure due to stack effect, mechanical systems and wind." While this performance of effective air barriers for housing has been extensively demonstrated, ongoing problems in nonresidential buildings indicate that further guidance would be helpful. To define "effective," regulatory authorities can refer to the Appendix of Part 9, the requirements in Part 5 and local construction practices that demonstrate adequate performance. The discussion and supporting material in the Appendix of Part 9 imply the use of materials with low air permeability in the air

Figure 2. Building governed by Part 9 of the National Building Code

barrier system. It provides a list of materials considered to have low air permeability, all of which have air leakage characteristics that are 0.02 L/(s•m^2) at 75 Pa or less, as required in Part 5. Some of these materials, because of their mechanical properties, will require additional structural support.

Subsection 9.25.3. provides requirements for continuity of the air barrier system and identifies specific joint and intersection details where continuity must be maintained. These include:

- joints in panel-type or sheet materials;
- interfaces between building envelope components, such as wall/window and wall/door interfaces (in this case the wall, window and door components together with the wall air barrier system tie-ins form the complete air barrier system);
- intersections between building envelope assemblies and interior walls and floors; and
- penetrations through the air barrier system (for hatches, wiring, piping, ductwork, chimneys, and others).

This is not a comprehensive list; the fundamental requirement is for a continuous air barrier system. The details listed do, however, identify areas where some practices, though acceptable in the past, may no longer be adequate.

3.2.2 Structural Capacity and Durability

Rather than providing quantitative requirements for structural capacity and durability, Part 9 again relies on the article requiring "an effective barrier to air exfiltration under differential air pressure due to stack effect, mechanical systems and wind." Clearly, to be effective the air barrier system must be able to resist wind forces over the service life of the building. (The wind forces were more specifically identified in Part 5.) An approach to defining loads on the air barrier system is specified in the CCMC Technical Guide and explained further in this publication.

3.2.3 Relationship Between Air Barrier Systems and Vapour Barriers

Part 9 requires that most envelope assemblies, including walls, be constructed with a vapour barrier providing the required resistance to water vapour diffusion when the wall is subjected to a temperature and water vapour pressure differential. The maximum allowable initial vapour diffusion rate for the vapour barrier in any wall assembly is specified at 45 ng/(Pa•s•m^2). It should be noted that the aged value for vapour diffusion in CAN/CGSB-51.33-M89, "Vapour Barrier Sheet, Excluding Polyethylene, for Use in Building Construction," is 60 ng/(Pa•s•m^2). This therefore becomes the acceptable aged value for vapour diffusion. For assemblies requiring a high resistance to vapour diffusion, that is, in assemblies using low vapour permeance sheathings or cladding, the maximum allowable vapour permeance is reduced to 15 ng/(Pa•s•m^2).

The NBC recognizes that the material in the air barrier system that provides the main resistance to air movement and the vapour barrier may or may not be one and the same. If the functions are separated, the vapour barrier need not meet the continuity or structural requirements of air barrier systems. If they are combined, there is a restriction on where the system can be located with respect to thermal insulation for condensation control.

The restriction, as per article 9.25.1.2., to reduce the risk of condensation is: Any material, whether part of an air barrier system or not, having an air permeance of less than 0.1 L/(s•m^2) at 75 Pa and a vapour permeance of less than 60 ng/(Pa•s•m^2) must be placed:

- on the warm side of the insulation, or
- with a minimum portion of the insulation placed outside of it (see Table 2), or
- outside a drained and vented cavity.

The first two restrictions could apply to components of the air barrier system and would apply to other materials with these properties that are not designated components of the air barrier system. The last does not apply, because a material outside a drained and vented cavity cannot form part of a continuous air barrier system.

Table 2. Ratio of outboard to inboard thermal resistance*

Heating Degree Days at Building Location (Celsius degree - days)	Minimum Ratio
up to 4999	0.20
5000 to 5999	0.30
6000 to 6999	0.35
7000 to 7999	0.40
8000 to 8999	0.50
9000 to 9999	0.55
10000 to 10999	0.60
11000 to 11999	0.65
12000 or higher	0.75

Note: The ratio is the total thermal resistance outboard of a material's inner surface to the total thermal resistance inboard of the material's inner surface.

* Further detail appears in Table A-9.25.1.2.A. of the NBC, and Figure 10 on page 22.

4. CCMC TECHNICAL GUIDE FOR EVALUATION OF AIR BARRIER SYSTEMS FOR EXTERIOR WALLS OF LOW-RISE BUILDINGS

With the changes incorporated in the 1995 NBC and the introduction of new materials and methods for providing air barrier systems in walls, an accepted method of evaluating the effectiveness and durability of air barrier systems is needed. In this context, building product manufacturers, in partnership with NRC and the Canadian Home Builders' Association, funded the development of a technical guide for the evaluation of air barrier systems for exterior walls of low-rise buildings. The Canadian Construction Materials Centre (CCMC) at NRC's Institute for Research in Construction coordinated the project. As requests are made to CCMC for the evaluation of specific air barrier systems, this *Technical Guide* will be used as a basis for the evaluations.

The guide's methodology, requirements and criteria were developed to evaluate the performance of air barrier systems for walls of buildings up to three stories high. An air barrier system that has been evaluated to the criteria would be deemed to comply with the intent of the NBC for these low-rise applications, provided it is constructed in conformance with the guide's requirements.

In some cases the deemed compliance would be based on using the equivalence provisions in Section 2.5 of the NBC rather than prescriptive requirements; for example, some of the materials may have air leakage characteristics greater than 0.02 $L/(s \bullet m^2)$ at 75 Pa. This flexibility is afforded by focusing the evaluation on the characteristics of the 'proprietary' air barrier system rather than having to address all combinations of possible materials, components and systems as must be done within the NBC.

Compliance with NBC equivalence provisions does not require evaluation by CCMC. However, CCMC is the only organization recognized in Canada to provide published third-party evaluations and is often used by building officials for this purpose.

4.1 Technical Criteria and Associated Rationale

Technical criteria within the *Technical Guide* focus on the air leakage characteristics of the system, its structural capability, and issues of continuity and durability.

4.1.1 *Maximum Allowable Air Leakage Rates*

The assessment of the maximum air leakage rate is based on total system leakage, including anticipated joints, connections and penetrations. Table 3, taken from the *Technical Guide*, lists the maximum allowable leakage rates for a building with indoor relative humidity levels up to 35%. Note that the allowable leakage depends on the water vapour permeance (WVP) of the outermost (non-vented) layer of the wall assembly. The rationale for this approach is provided in Section 4.1.2 below.

4.1.2 *Rationale for Determining Permissible Air Leakage Rates*

It is now generally accepted that the leakage of moist, heated interior air into cold spaces of building envelope assemblies is a far more significant cause of problems resulting from condensation than the diffusion of water vapour. The most important function of a wall air barrier system is to control the flow of air into and through a wall, so that:

- condensation is rare or the quantities of water accumulated are small, and
- drying is rapid enough to avoid the deterioration of materials or the growth of molds and fungi, which are not only health concerns but also agents of deterioration.

Table 3. Permissible wall air barrier system air leakage rates and respective water vapour permeance

Water Vapour Permeance of Outermost (Non-Vented) Layer of Wall Assembly[1,2] ng/(Pa•s•m²)	Maximum Permissible Air Leakage Rates[3,4] L/(s•m²) at 75 Pa
15 < WVP <60	0.05
60 < WVP < 170	0.10
170 < WVP < 800	0.15
> 800	0.20

Notes:

1. For an air barrier system installed on the cold side, adjacent to a vented space, this value would be the WVP of the most water vapour impermeable material of the air barrier system. For air barrier systems located within the wall assembly (i.e., toward the warm side within the insulation), this value would apply to the material with the lowest WVP outboard of the air barrier system and inboard of any vented space.
2. The CCMC evaluation report will state that where the designated air barrier system is located within the wall assembly there must be **no material installed outboard** of the air barrier system that has a lower WVP for the respective air leakage rating.
3. The maximum permissible air leakage rate for an air barrier system within any of the first three categories of WVP ranges may be increased by 0.05 L/(s•m²) at 75 Pa, to a maximum of 0.2 L/(s•m²) at 75 Pa, if the air barrier system is insulated in accordance with Table 2 for the respective geographical location. The maximum permissible air leakage rate of 0.2 L/(s•m²) at 75 Pa is a cut-off point based on acceptable heat loss into the wall assembly.
4. For proponents of an air barrier system in buildings operating at relative humidities greater than 35%, CCMC will establish the permissible air leakage rate case by case.

Determining the relationship between air leakage and moisture accumulation requires complex mathematical analysis. One of the key research projects carried out during the development of the CCMC *Technical Guide* investigated this relationship by computer simulation. A study was carried out by IRC and the Technical Research Centre (VTT) in Finland, using a jointly developed computer model, to evaluate the effect of various parameters (air leakage, water vapour permeability, weather, insulation levels, and location) on the amount of condensation that is likely to occur inside a typical wood-frame wall assembly.

In deciding what modelling assumptions it should work with, the project team relied on previous research findings to define common construction features that would make a wall system more susceptible to condensation. These features included the following:

- The wall would be well insulated. High insulation levels keep the outer portions of the wall cooler.
- The most airtight surface would be at the outer sheathing layer. (This situation could easily occur when low-permeability sheathings are used in conjunction with penetrations of the interior

sheathing or when the air barrier system is located on the cold side.)

- The entry of exfiltrating air into a particular wall cavity would be at a single leakage point.
- The wall would operate under a slight exfiltrating pressure. (This pressure is commonly created by stack forces or mechanical ventilation. In addition, there are exfiltrating and infiltrating pressures that are created by wind.)

The composition of the simulated stud cavity is illustrated in Figure 3. An air barrier system is located on the exterior of the assembly. Air leakage is simulated through a hole such as an electrical outlet in the interior finish. Air leakage through this single hole then exfiltrates through the exterior air barrier system in a uniformly distributed fashion. The climates of Edmonton, Halifax and Ottawa were simulated for temperature, wind pressure, wind direction, and vapour pressure while a positive baseline air-pressure difference of 10 Pa was simulated across the wall.

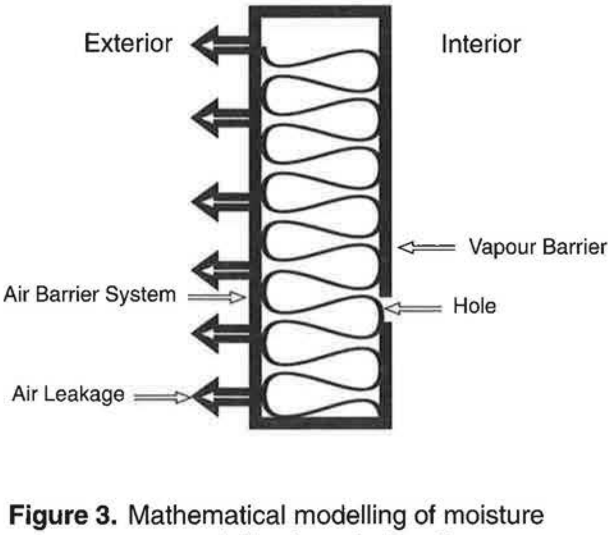


Figure 3. Mathematical modelling of moisture accumulation in a stud cavity

Mathematical modelling included the following:

- temperature
- air pressure
- vapour pressure
- thermal insulation
- leakage rate of air barrier system
- vapour permeance of air barrier system
- added insulation outside air barrier system

The modelling of the relationship between air leakage rates and moisture accumulation showed the complexity of the hygrothermal mechanism. Curve A in Figure 4 shows how moisture accumulation varies with leakage rate for one set of assumptions related to temperatures, humidity, insulation, and air barrier permeability. Note how moisture accumulation increases with leakage up to a certain point and then decreases as the increased heat from the leaking air warms the interior surfaces to a temperature above condensing. Very airtight or very leaky walls will not have a

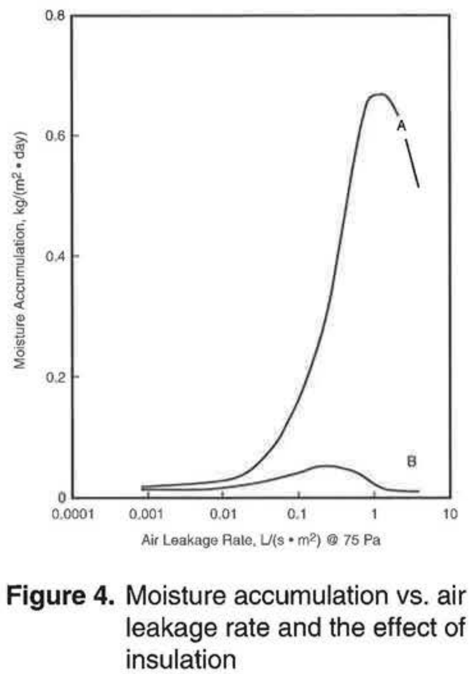


Figure 4. Moisture accumulation vs. air leakage rate and the effect of insulation

problem, whereas one with an intermediate level of airtightness may. The location of the crest for this moisture accumulation varies with the assumed temperature, humidity and insulation level. The accumulation rate and location of the "hump" changes dramatically, for example, if the air barrier[4] is kept warmer by placing some insulation outside the air barrier. Curve B in Figure 4 shows the effect of adding insulation with a thermal resistance of 0.75 $K \bullet m^2 \bullet W^{-1}$ (R4.3) outside the air barrier modelled in Curve A.

The simulation also indicated whether water would condense and be retained until the arrival of warm periods of the year, when mold and fungi are likely to grow. Figure 5 shows an example of a yearly moisture collection curve from the study. The largest accumulation of moisture occurred when:

- the air barrier system was outside the insulation,
- the assembly outside the insulation had a low water vapour permeance, and
- the indoor relative humidity level was high.

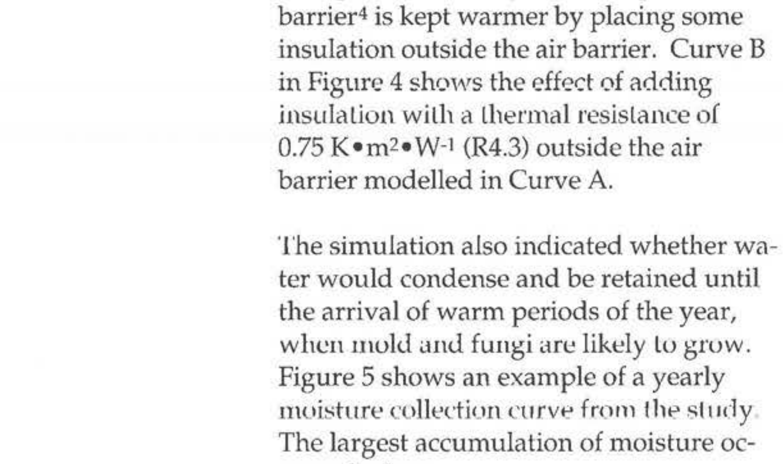


Figure 5. Total mass of moisture in the exterior 15 mm of insulation at the condensing surface with different air permeances of the air barrier layer and 60 $ng/(Pa \bullet s \bullet m^2)$ vapour permeance. For more information on the modelling conducted, see "Effect of Exfiltration on the Hygrothermal Behaviour of a Residential Wall Assembly," Tuomo Ojanen (VTT) & Kumar Kumaran (NRC), Journal of Thermal Insulation and Building Envelopes, Volume 19, January 1996.

Small differences were noted in moisture accumulation for the buildings modelled in the three cities at the end of the one-year cycle. The Halifax simulation indicated only a slightly lower moisture accumulation than that of Edmonton. This stems from the fact that, although the Edmonton winter is colder than that in Halifax, the drying potential to reduce cavity moisture is more limited in the Maritimes than in the Prairies.

Even if the arrangement of materials is such that air leakage does not result in moisture accumulation, a maximum air leakage rate for air barrier systems should be defined to control energy flow through the wall. The study showed that at an air leakage rate of 0.2 $L/(s \bullet m^2)$ at 75 Pa, the heat loss due to air leakage was approximately 15 percent of the conductive heat transfer through a simulated RSI 3.6 (R20) wall system. This rate of heat loss was accepted to be commensurate with the maximum allowable air leakage rate. The CCMC evaluation criteria consider both moisture collection potential and energy conservation to define the maximum allowable air leakage rate. Modelling with an external air barrier system and typical indoor humidity levels of up to 35 percent resulted in the maximum system air leakage rates shown in Table 3.

As indicated in the notes to Table 3, where insulation has been placed outside the air barrier system, a higher air leakage rate is possible without condensation. The CCMC evaluation criteria increase the allowable air leakage rate by 0.05 $L/(s \bullet m^2)$ at 75 Pa when the ratio of the insulation value of the wall outside the inner surface of the air barrier system is adequate. This ratio varies with geographic location.

[4] Note: This applies to the air barrier when it is installed on the cold side. If the air barrier is on the warm side, this effect applies to the condensing surface or sheathing on the cold side.

4.1.3 *How to Establish the Air Barrier Rating of a Tested Assembly*

The air leakage rates reported for full-scale test assemblies under the evaluation procedure are not merely those rates recorded during a single test at the 75-Pa pressure difference used for material characterization. A particular test sequence is specified for three test specimens. The air leakage tests are conducted over a spectrum of loadings up to 500 Pa. Air leakage data derived from the opaque wall tests (see Figure 6), conducted after structural loading tests as per 4.1.5 below, are then shown in a graph plotting air leakage versus pressure, and the value at 75 Pa is only accepted if the air barrier assembly has also provided good performance at higher pressures. This means that during the tests the air leakage rate of the specimen would perform linearly across the range of pressures. This is established by the testing agency using standard mathematical data fitting procedures. In addition, the air leakage of those test specimens with penetrations through or connections to other elements (see Figures 7 and 8) must not exceed the air leakage of the opaque wall by more than 10 percent. Thus, appropriate air leakage behaviour for all three specimens with no more than 10% variability constitutes the CCMC acceptance criteria if the air leakage rate falls within the permissible rates of Table 3.

Specimen 1 - Opaque Wall

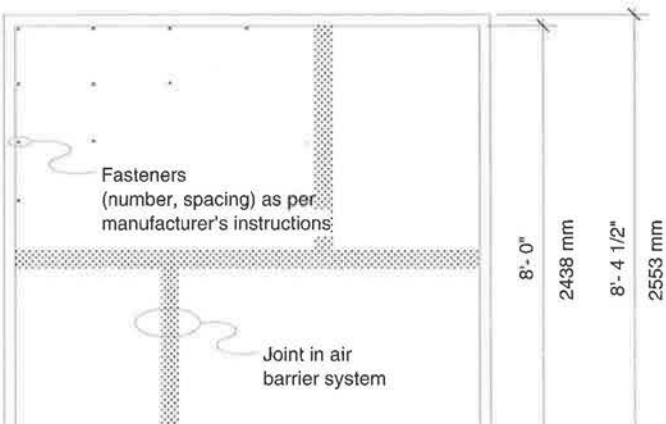


Figure 6. Opaque wall specimen used to obtain air leakage data

Specimen 2 - Continuity at Penetrations

(Base wall and air barrier configuration same as Specimen 1)

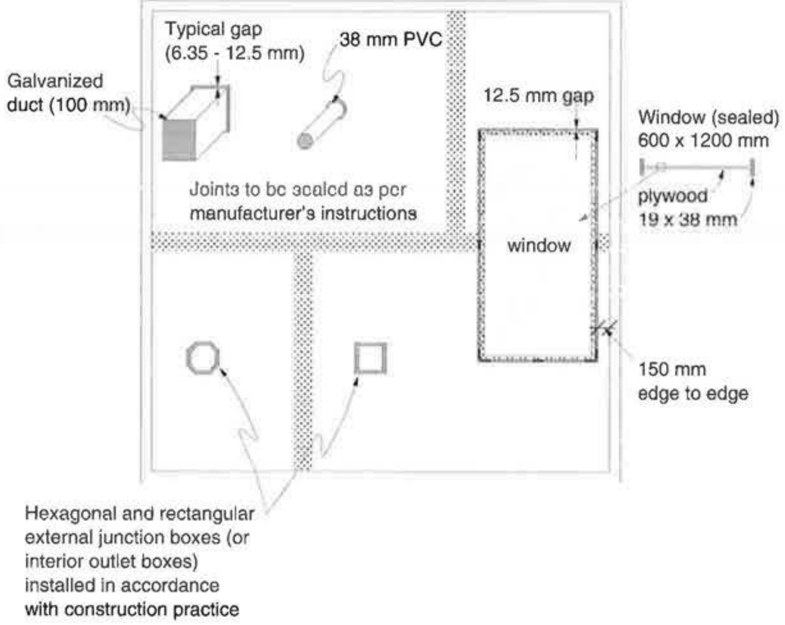


Figure 7. Test specimens with penetrations through the air barrier system.

Specimen 3 - Foundation interface and opaque wall (with modifications)

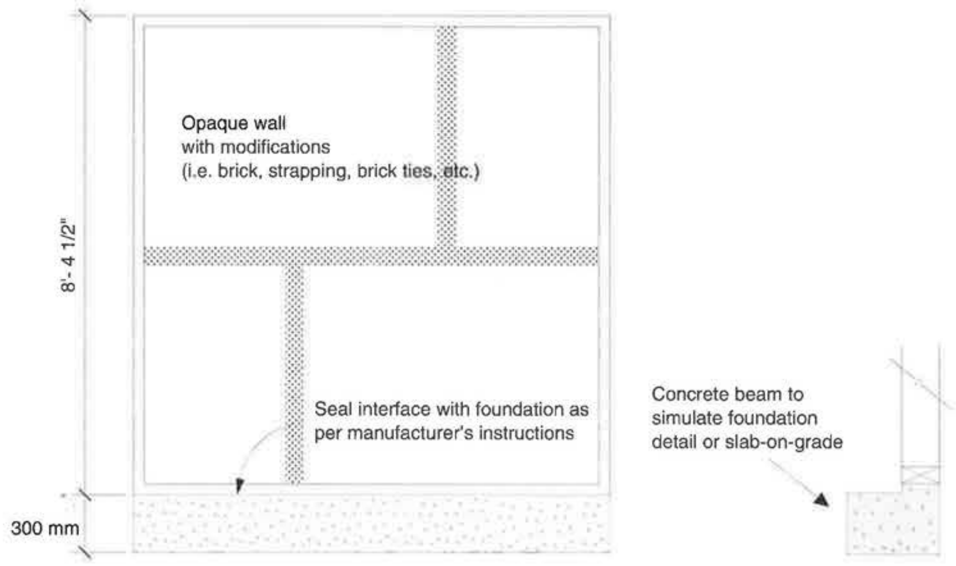


Figure 8. Test specimens with connections to other elements through the air barrier system.

4.1.4 Structural Capacity

The structural capacity of the air barrier system is determined by using procedures that test the air barrier system to the design wind pressure experienced by low-rise wall systems in most climates in Canada. In addition, the deflection at 150 percent of the wind pressure is measured and reported because the information is important to designers.

A wall system is subjected to lateral air pressure loads created by stack forces, mechanical forces, and wind. Stack forces and mechanical forces can be characterized as being relatively low in magnitude but long in duration; whereas wind forces, and particularly those associated with gusts, may be temporary but are much higher in magnitude.

4.1.5 Testing of Structural Capacity and Rationale

Because the air barrier system is by definition the most airtight plane in the wall, it will carry most of the air pressure loads. The designer has to assume that the air barrier system must be able to resist and transfer the full wind pressure to the building structure without damage to the air barrier system or other components of the wall system.

To evaluate the structural capacity of the air barrier system specimens in relation to expected wind loads, the specimens are tested for sustained, cyclic and gust loadings. The pressures for these tests shown in Table 4 are established in accordance with the 1-in-10-year return wind pressure for the geographical area in which the wall will be situated. These design load levels are consistent with wind loading for the structural design of glass for windows in Tables A-9.7.3.2.A and A-9.7.3.2.B of Part 9 of the NBC, since windows are part of the air barrier system for the building.

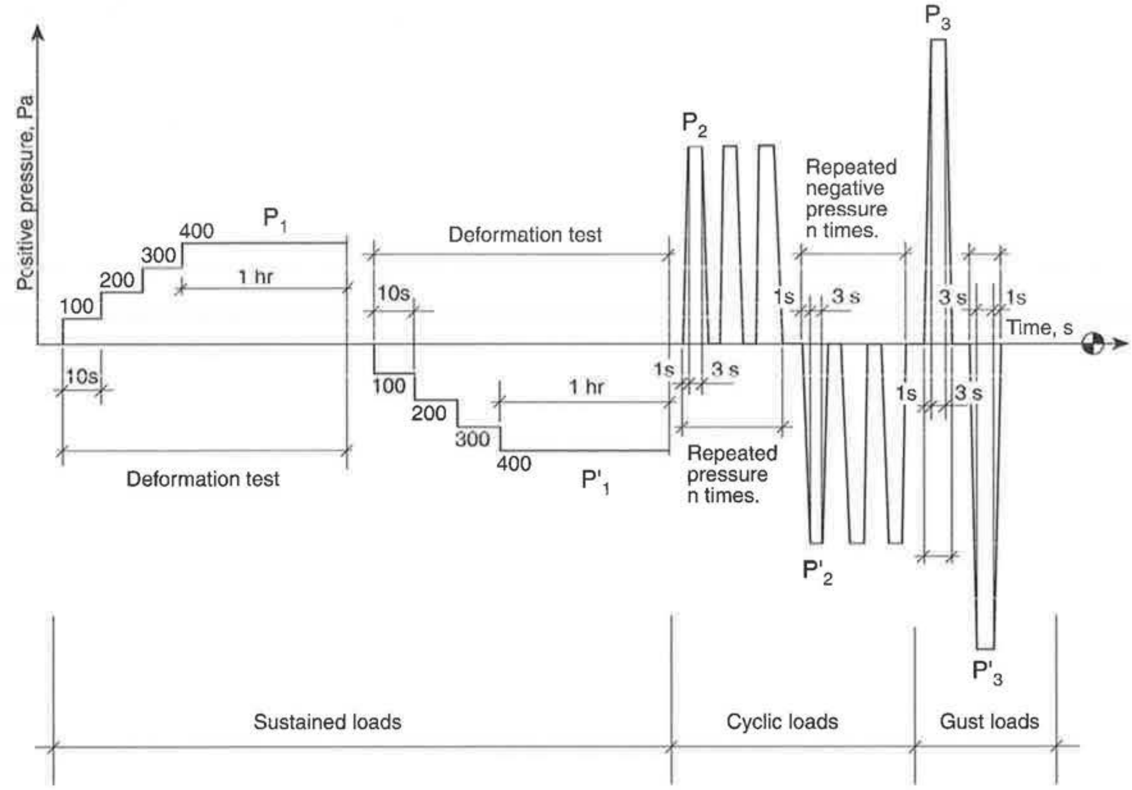
Table 4. Wind pressures established in accordance with the 1-in-10-year return wind load for the geographical area

For Geographical Areas Where Wind Design Value is (kPa)	P_1,P_1' Sustained for 1 h (Pa)	P_2,P_2' 2000 Cycles[1] (Pa)	P_3,P_3' Gust Wind (Pa)
$Q_{10} < 0.40$	400	530	800
$Q_{10} < 0.60$	600	800	1200

See Figure 9 for reference to P_1, P_1', P_2, P_2', and P_3, P_3'.

[1] The 2000 cyclic loads could be applied in four stages of 500 cycles, reversing from positive to negative pressures; or in two stages of 1000 cycles, reversing from positive to negative.

Structural (Wind) Loading Schedule



● air leakage rate and deflections to be established after structural loading

Figure 9. Structural (wind) loading schedule

Table 5. Deflection of the air barrier system at specified loads

Wind Design Value (kPa)	Record Maximum Deflection(s) after Completion of Wind Pressure Loading[1]
$Q_{10} < 0.40$	$D_{0.40}$ @ 640 Pa
$Q_{10} < 0.60$	$D_{0.60}$ @ 960 Pa

[1] The wind pressure loading shall be maintained for a minimum of 10 s and the maximum deflection, at any point on the specimen, from the supporting member of the air barrier system shall be determined for both positive and negative pressures. The loadings are 1.6 times Q_{10} from adjustments for exposure in urban areas.

The wind loads are applied according to Figure 9 and the test pressures and cycles are thought to be representative of the wind pressures and fatigue on the air barrier associated with two or three major storms which any building would likely experience during a 10-year period.

The material providing the principal plane of airtightness of the air barrier system need not rely on its own strength to resist these structural loads. A flexible membrane can be supported by another material or a framing system that is more air permeable but has the necessary structural strength and rigidity. Any proprietary air barrier system must identify both the plane of airtightness component and its structural components, such as substrates and fastenings, which are part of the 'system.'

Deflection of the air barrier system is measured at the loads shown in Table 5, which is taken from the CCMC *Technical Guide*.

Deflection of the air barrier system under load can:

- place wind loads on surfaces that were not designed to support them,
- displace other materials in the wall system, and
- result in tension loads in the membrane (or joints) and affect its long-term service life.

The wall design must accommodate the deflection of the air barrier under full load and it must also allow some margin for construction tolerance. The CCMC evaluation criteria and Part 5 of the NBC are based on the premise that the design should accommodate the degree of air barrier system deflection that would occur if 1.5 times the design wind load were placed on it. With the CCMC evaluation procedure, this level of deflection is measured and reported.

It should be noted that with a flexible membrane supported on a framing system the ability to resist lateral loads depends on the ability of the membrane and joints to resist tensile forces. This requires that joints in the membrane and to adjacent construction be detailed to provide the required strength. This is usually done by clamping the joints between rigid members.

Air barrier system rigidity also affects the performance of rainscreen walls. If the air barrier deflects, it allows more of the dynamic pressure load to be borne by the exterior cladding. This can increase the level of rain penetration (refer to Chapter 6 for more details.)

4.1.6 Continuity

The *Technical Guide* addresses continuity within the air barrier system by requiring testing of specimens that contain fasteners, joints and connectors to adjacent construction as shown in Figures 6 to 8. The air leakage test results on these specimens after structural loading must not vary by more than 10 percent from the opaque wall system air barrier to meet the requirements for continuity.

4.1.7 Durability

Durability can be defined as the ability of a building component to perform its required functions over a period of time in the environment to which it is exposed.

The durability of an air barrier system depends on compatibility with adjacent materials and the loads to which it is subjected over its service life. The factors in the local environment that can play a role include temperature, moisture, solar radiation, electrochemical factors, and biologically active material. The required durability of any material or system depends on how long it is intended to perform and whether it can be maintained or economically repaired. Some air barrier systems are accessible for maintenance, but many are not because they are incorporated within the wall construction. The CCMC *Technical Guide* requires that inaccessible air barrier systems be considerably more durable than accessible and repairable ones.

CCMC has defined durability criteria based on the accessibility of the air barrier system and the specific materials used. Currently, criteria have been developed for spray-in-place foam plastic insulation, rigid insulation, exterior non-paper-faced gypsum board, polyethylene- and polypropylene-based membranes, flexible PVC sheets, and modified-bitumen membranes.

The CCMC evaluation criteria address durability by evaluating each material according to standard tests that simulate aging, climate and repeated use. (The tests were developed by ASTM, CGSB, and other standards-writing organizations.) In addition, accelerated-aging protocols have been added to the *Technical Guide*, and acceptance criteria have been set based on residual strength and air permeance after accelerated aging.

4.1.6 Other Requirements

Other requirements in the CCMC *Technical Guide* are based on ensuring that air barrier systems are supplied and installed at a consistent quality equal to that tested during the evaluation. Requirements to this end include:

- testing of representative specimens,
- provision of an installation manual,
- provision of a quality assurance plan developed by a third party or under ISO 9000, and
- providing for site inspection of installations over the first year after evaluation in some cases.

4.2 The CCMC Evaluation Process

The CCMC evaluation process assesses the entire air barrier system as a product. A product manufacturer – subsequently called the 'proponent' – makes application to CCMC for an evaluation as follows:

- The proponent provides CCMC with company information, a sample of materials and a description of the air barrier system, and detailed installation instructions.
- CCMC provides the proponent with testing methods and evaluation criteria presented in the *Technical Guide for Air Barrier Systems for Exterior Walls in Low-Rise Buildings*, together with a list of acceptable third-party testing laboratories.
- CCMC reviews the proponent's quality assurance program, which may be ISO 9000 certification, a program under the control of an accredited agency, or an internal corporate quality control procedure acceptable to CCMC.
- A third party visits the proponent's facility and takes samples for testing.
- The proponent has the product tested (test specimens are fabricated to be representative of how the system is fabricated in the field) by third-party laboratories who submit the results directly to CCMC.
- CCMC assesses the product, test results, engineering analysis, installation instructions, and delivery system to the field against the criteria established in the *Technical Guide*.
- CCMC writes an evaluation report with limitations on the use of the product that may be necessary to eliminate concerns, such as climate limitations, interior humidity levels, or type of construction.
- CCMC's evaluation report is then published in the CCMC *Registry of Product Evaluations*.

5. REVIEW AND ACCEPTANCE OF WALL AIR BARRIER SYSTEMS

Air barrier systems that have been evaluated by CCMC can be deemed to meet the requirements of the NBC if all materials used in the system have been installed properly in the field so that they perform as evaluated. The system is to be installed according to the evaluated installation manual, and the application must be within any limitations defined by the CCMC evaluation.

5.1 Design Review

Where the air barrier system has not been evaluated by CCMC, the design review procedure described here is suggested.

5.1.1 Materials

The design review procedure should answer the following questions with respect to air permeance, water permeance, compatibility and durability of the materials specified for the air barrier system.

Are the specified materials tight enough?

There is currently only limited information about the air permeance of materials. Manufacturers have had little reason to provide such information. In a 1988 research study,[5] CMHC obtained air leakage data for a number of common construction materials. The air permeance data in Table 6 are drawn from this source. It identifies materials that have air permeance values of 0.02 L/(s•m²) or less at 75 Pa, which meet the NBC Part 5 requirement for a material that provides the principal resistance to air leakage used in an air barrier system. As mentioned previously, some of these materials would require additional structural support to perform adequately in an air barrier system.

Are materials compatible with those it contacts?

Compatibility information is best drawn from the manufacturer's information. Some known incompatibilities that should be watched for include:

- polyvinyl chloride (PVC) and asphalt-based materials
- polyethylene and asphalt-based materials
- polystyrene and asphalt-based cutback materials

Are materials adequately durable?

Currently, the leading source of information about durability of air barrier system materials is CCMC's *Technical Guide*. Tables developed for it represent the best current expertise regarding tests and criteria for assessing and defining durability of 17 materials and accessories for air barrier systems. Since durability is such an important element of the CCMC evaluation and the new CSA S478, *Guideline for Durability in Buildings*, designers and regulators can soon expect more extensive information about durability to be issued by manufacturers and testing agencies. Internationally, some countries are further defining durability expectations. New Zealand's 1995 Building Code, for instance, requires a service life of 50 years for structural elements and hidden anchors within the building envelope and between 5 and 15 years of service life, depending on the ease of access, for other building envelope elements.

[5] Bombaru, D., R. Jutras and A. Patenaude. *Air Permeance of Building Materials*. Summary Report prepared by AIR-INS Inc. for Canada Mortgage and Housing Corporation, 1988.

Table 6. Air and vapour permeance data for common construction materials

Material	Air Permeance	Vapour Permeance	Notes
	Measured Leakage 75 Pa L/(s•m²)	ng/(Pa•s•m²)	(see below)
Construction Materials			
9.50-mm (3/8-in.) plywood sheathing	0.00	15-50	1, 2
8.00-mm (5/16-in.) plywood sheathing	0.0067	18-59	1, 2
15.9-mm (5/8-in.) flakewood board (OSB)	0.0069	30	1, 2
11.0-mm (7/16-in.) flakewood board (OSB)	0.0108	44	1, 2
15.9-mm (5/8-in.) particle board	0.0260		
12.7-mm (1/2-in.) particle board	0.0155		1
12.7-mm (1/2-in.) cement board	0.00	54-108	1
11.0-mm (7/16-in.) plain fibreboard	0.8223		
11.0-mm (7/16-in.) asphalt impregnated fibreboard	0.8285	772-2465	
3.00-mm (1/8-in.) hardboard (standard)	0.0274	630	
12.7-mm (1/2-in.) foil back gypsum board	0.00	0.00	1, 2
12.7-mm (1/2-in.) gypsum board	0.0091	1373	1
Tongue and groove planks	19.1165	982	
2.70-mm (3/32-in.) modified bituminous torch on grade membrane (polyester reinforced mat)	0.00	4.0	1, 2
2.70-mm (3/32-in.) modified bituminous torch on grade membrane (glass fibre mat)	0.00	4.0	1, 2
1.50-mm (1/16-in.) modified bituminous self-adhesive membrane	0.00	01.9	1, 2
1.50-mm (1/16-in.) smooth surface roofing membrane	0.00	3.4-3.7	1, 2
13.6-kg (30-lb) roofing felt	0.1873	160	
6.8-kg (15-lb) non-perforated asphalt felt	0.2706	320	
6.8-kg (15-lb) perforated asphalt felt	0.3962	800	
Plastic and Metal Foils and Films			
0.15-mm (6-mil) polyethylene	0.00	1.6-5.8	1, 2
0.03-mm (1-mil) aluminum foil	0.00	0.00	1, 2
Reinforced non-perforated polyolefin	0.0195		1
Spunbonded polyolefin film	0.9593	3646	
Spunbonded polypropylene film	3.2186	884	
0.10-mm (4.00-mil) Type I perforated polyethylene	4.0320		
0.10-mm (4.00-mil) Type II perforated polyethylene	3.2307		
Thermal Insulations			
38.0-mm (1.5-in.) extruded polystyrene	0.00	15-60	1, 2
25.4-mm (1-in.) foil back urethane insulation	0.00	0.00	1, 2
25.4-mm (1-in.) phenolic insulation board	0.00	133	1
50.8-mm (2-in.) phenolic insulation board	0.00	67	1
25.0-mm (1-in.) expanded polystyrene - Type II	0.1187	86-160	
Glass fibre rigid insulation board with spunbonded polyolefin film on one face	0.4880	1143	
25-mm (1-in.) expanded polystyrene - Type I	12.2372	115 - 333	
152-mm (6-in.) glass fibre wool insulation	36.7327	1110	
Vermiculite insulation	70.4926	1666	
Cellulose insulation (spray on)	86.9457	1666	

Notes: 1 = air permeance less than 0.02
2 = air permeance < 0.1 and vapour permeance < 60

Are relevant material standards met?

There is currently only one referenced standard in the NBC for materials used as part of the air barrier system in walls. Part 9 references CAN/CGSB 51.34-M for polyethylene sheet used as part of the air barrier system.

Where a material is (a) intended to perform another function in the assembly, such as to provide the required vapour diffusion resistance (vapour barrier), thermal resistance (insulation), or moisture protection, and (b) covered by a referenced standard, it must conform to that standard. For example, both Part 5 and Part 9 of the NBC reference three standards dealing with vapour barrier materials:

CAN/CGSB-51.33-M, *Vapour Barrier Sheet, Excluding Polyethylene, for Use in Building Construction*

CAN/CGSB-51.34-M, *Vapour Barrier, Polyethylene Sheet for Use in Building Construction*

CAN/CGSB-1.501-M, *Method of Permeance of Coated Wallboard.*

Part 5 does not provide a water vapour permeance value nor does it require that the material providing vapour diffusion resistance be subject to one of these standards. However, if the material used falls within the scope of one of these standards, it must comply with it. For example, a peel-and-stick, modified-bitumen membrane does not fall within the scope of any of these standards, yet is generally an accepted air and vapour barrier material. If a polyethylene sheet is used as the combined air and vapour barrier, it must conform with CAN/CGSB 51.34-M.

Part 9 is less flexible. It prescribes a water vapour permeance value of 45 ng/(Pa•s•m^2) to be met. Part 9 also requires that a vapour barrier conform to one of these standards where a high resistance [15 ng/(Pa•s•m^2)] to vapour movement is required. If a peel-and-stick membrane is to be used as the air barrier, a separate vapour barrier (even painted wall board conforming to CAN/CGSB-1.501-M) is required in the assembly. Alternatively, the adequacy of the peel-and-stick membrane, serving a dual role, may be demonstrated according to the equivalency provisions in Section 2.5 of the NBC.

5.1.2 System Design

Is there sufficient insulation on the cold side of low-vapour-permeance materials?

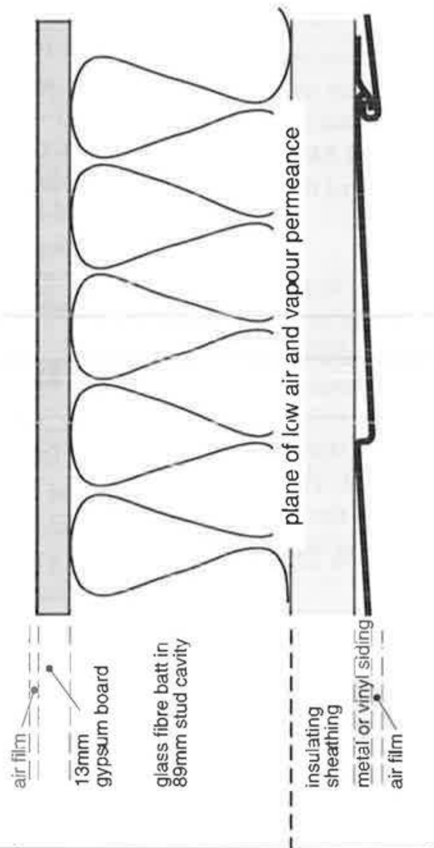
Part 9 of the NBC requires that any sheet- or panel-type material installed on the cold side of a wall assembly that has a vapour permeance of less than 60 ng/(Pa•s•m^2) and an air leakage rate of less than 0.1 L/(s•m^2) at 75 Pa, must have a certain proportion of the insulation on the cold side of the material or be vented. Figure 10 shows how the ratio is calculated, and Table 2 shows the minimum ratio required for different climate zones.

Water vapour permeance data can be drawn from manufacturers' product information or such sources as ASHRAE. Table 6 provides vapour permeance data for some materials. It identifies those with air permeance of less than 0.1 L/(s•m^2) at 75 Pa and a water vapour permeance of less than 60 ng/(Pa•s•m^2) that are subject to restricted locations.

Part 5 does not contain such a prescriptive requirement, because designers must take into account the effects of low air and vapour permeance materials in their building envelope designs.

Are provisions made for continuity at all joints?

The air barrier system within the opaque wall must form a singular plane of airtightness throughout the building envelope assembly. In the design review, it should be



	Inboard			Outboard		
RSI value	0.12	0.08	2.11	0.87	0.12	0.03
Total RSI value	2.31			1.02		
Ratio	$\frac{1.02}{2.31} = 0.44$					

Figure 10: Calculated ratios

clear from the drawings how this plane of airtightness is carried from one low-air-permeance material to another. At each junction it should be clear how the air barrier airtightness continuity is maintained. The sealing method must allow for the movement that can be expected at that joint, and the joint must be buildable considering access and construction sequencing.

Table 7 provides joint details in a wall assembly that must be considered.

Some of the most difficult details to design, and therefore the most important to review, are locations where these usually linear joints intersect or where the plane of airtightness in the wall changes.

Have provisions been made for continuity at major building envelope intersections?

The designer and building official must assure themselves that continuity exists within the complete building envelope system. This will require that the details of the wall system discussed in this section will connect appropriately to the roof or ceiling air barrier systems and be continuous at the foundation or slab. This will normally require connection and support for the air barrier system from the wall to the waterproof membrane in the case of a flat roof, or connection to the air barrier system in the ceiling in the case of ventilated roofs. Whether the fastening system is actually suitable may require testing or engineering analysis.

5.1.3 Structural Support

Is the air barrier system supported or strong enough to resist inward and outward wind loads?

The air barrier system must resist full wind loads and transfer these to the wall structure. Most air barrier systems are placed on one side of the structural components of the back-up wall so that the critical issue is the degree of support and attachment for loads acting in the opposite direction. Detailed specification of the fastening system, including number, size and location of fasteners for the air barrier system is required. This information must be provided when the proprietary system is submitted for acceptance.

Table 7. Joint details in wall assemblies

Joint	Special Notes	Notes
Between panels of air barrier materials		1,2
Between sheets of air barrier materials	Joint design must consider resistance to tension loads.	
	Part 9 requires sealing or lapping and clamping between rigid members.	1,2
At interfaces in walls of differing construction interfaces to roof or floor air barrier systems at base of walls		2
Across structural expansion joints	Must often accommodate a high degree of movement.	
Across junction of interior floor to exterior wall		
Across junction of interior wall to exterior wall		1
Where an interior wall projects through a wall or ceiling to become an exterior wall		1
Where a roof meets a higher wall		1
Where a floor overhang meets an exterior wall		1
At connection to the frame of windows, doors, and sloped glazing		1,2
At fasteners		2
At penetrations for services such as wiring, piping ducts, and electrical boxes	Must often accommodate a high degree of movement.	1,2
At penetrations for chimneys and gas vents	Must be done in a non-combustible manner.	1
Wall to soffit junctions		
At penetrations for brick ties, insulation clips, and structural support of elements beyond the air barrier		2

Notes:
1 = Specifically listed in Part 9   2 = Included in CCMC Test Specimens

Will the air barrier system deflect and what are the consequences of this deflection?

Where the air-barrier system will deflect, the wall design must accommodate the expected level of deflection without adverse consequences, such as

- displacing other materials in the wall,
- placing loads on surfaces not designed for them, or
- placing tension loads on joints not designed for them.

With wood-frame buildings up to three stories high, the deflection of a membrane air barrier (i.e., polyethylene) sandwiched between the frame and a sheathing layer (i.e., gypsum wallboard) is adequately controlled. If an exterior membrane that is not adhered to a substrate is employed as an air barrier, a method of resisting outward wind forces must be provided. The amount of deflection experienced initially and the increase in deflection due to fatigue can only generally be qualified in a test.

5.2 Field Review During Construction

The construction review of the air barrier system is intended to determine whether the materials and construction details being employed conform generally with the approved design and specifications, the application conditions are suitable for the materials and methods being used, and the continuity of the air barrier is provided and maintained during construction.

The construction review process also provides a last opportunity to find and resolve problems with continuity and structural support aspects of the design that were not noted during the design review.

A critical issue with construction review is the scheduling of inspection. Most air barrier systems in walls are part of an integrated wall design that cannot be inspected at completion, yet their integrity can be compromised at any time from installation up to completion. To review visually all the aspects of the construction that could have an effect on their performance would require virtually full-time inspection.

One highly recommended practice is the use of construction mock-up sections. In this process, typical areas of the wall system, which include common interface details, are designated as mock-up sections. The tradespeople complete these sections of the wall in the sequence planned for the entire building. The mock-up construction can be closely supervised, inspected and tested, if necessary. Interaction between tradespeople can be discussed and modified, if needed. The methods and quality of the work used to successfully obtain the required performance in the mock-up sections would form the basis for acceptance of the entire wall construction. These mock-up sections are often left as part of the finished building or may be retained separate from the building to serve as a reference throughout the construction stage.

5.2.1 CCMC-Evaluated Systems

If a CCMC-evaluated air barrier system is specified, the construction review process should:

- determine whether all materials used in the system are the same as those used when the system was evaluated. This includes substrates, sealants, coatings, and fasteners in addition to the sheet or panel elements that make up the air barrier system;
- ensure that the installation methods conform to the installation manual provided by the proponent of the evaluated system; this includes details of
  - conformance with environmental conditions during installation,
  - protection during the construction period,
  - preparation and sealing methods of all joints,
  - attachment methods and fastener spacing,
  - construction sequencing,
  - specific quality control or field testing;
- ensure the training and certification of installation personnel, for example, licensed and trained installers, supervised skilled tradespeople, or third parties relying on manufacturer's installation instructions.

5.2.2 Part 5 Systems

In a building designed according to Part 5, the design professional takes responsibility for material selection, system design, and installation requirements. The construction team is responsible for providing a continuous air barrier system that is constructed to specifications and ensuring that its integrity is maintained through to completion of construction. The construction review process should confirm that the requirements specified by the design professional are met. This typically requires that:

- all materials are either as specified or have been substituted on approval from the design professional; and
- installation procedures meet the design specifications, recommendations and limitations stated by product manufacturers.

Construction review should place particular emphasis on verifying:

- continuity at all joints,
- attachment methods, and
- fastener spacing.

(Table 7 could form the basis of a checklist of those details to be reviewed.)

5.2.3 Part 9 Systems

Part 9 does not require that a design professional participate in the design. Ensuring that a continuous, effective air barrier system is installed and that it conforms to building code requirements becomes the responsibility of the builder.

Assuming that the questions raised in the design review (see Section 5.1) are addressed, the construction review should particularly emphasize the verification of:

- continuity at all joints and interfaces,
- attachment methods, and
- fastener spacing.

(Table 7 could form the basis of a checklist of those details to be reviewed.)

5.3 Testing of Air Barrier Systems

The CCMC evaluation process relies very heavily on testing of sample specimens of air barrier systems. The Appendix of Part 5 of the NBC recommends that testing of air barrier systems be carried out when using a system whose performance is not known. Establishing a test program and defining the evaluation criteria based on that test program requires an understanding of testing procedures, methods and system requirements.

The overall system air leakage through the opaque portion of the wall assembly is the basis for the CCMC evaluation criteria and the system air leakage recommendation in the Part 5 Appendix. The CCMC requirements are based on testing sample wall sections in a laboratory using methods defined in ASTM E283[6] in which the air leakage through a wall assembly tested at a 75-Pa pressure difference is determined. This test requires isolating the section to be tested by creating a chamber around it within which the required air pressure and the flow required to maintain it can be measured. This procedure can be applied to small sections (perhaps those containing a specific type of joint) to a larger test section (incorporating a significant area of wall and joints) or in some cases, *in situ* in the field. Field-testing requires that the suitable section of the wall can be isolated from the remainder of the wall and form one side of the test chamber. In any of these cases some expertise is required to evaluate the results and some specialized

[6] ASTM E283-91 *Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtainwalls, and Doors Under Specified Pressure Differences Across the Specimen.* American Society for Testing and Materials, Philadelphia, U.S.A., 1991.

equipment is required. System air leakage levels can also be evaluated by the following methods:

1. Assessing air leakage rates through wall sections of sheet or membrane material and unit lengths of joints. Summing the expected leakage from these sources over a typical area provides the system air leakage levels, assuming no other penetrations or transitions exist.
2. Undertaking laboratory testing of a larger-scale test section that includes joints, penetrations and any interfaces that could be expected in the building. This would be analogous to the testing carried out for a CCMC evaluation.
3. Conducting *in situ* testing of an on-site mock-up may require inclusion of elements that allow isolation of the test section that may, however, not be part of the typical wall design.

The testing provides an air leakage rate for the test section. It does not necessarily determine where the leakage is occurring or what measures need to be taken to control it. Locating leakage points is often more simply done by creating a pressure difference and using visible tracers such as smoke. Smoke-testing, however, does not measure the flow.

It should be noted that a whole-building airtightness test, such as the one described in the Standard CAN/CGSB-149.10-M86[7] and proposed standard CGSB B149.15[8] does not provide measurements that can be directly compared with the system air leakage rates identified in the NBC or CCMC evaluation criteria. Typical results from such whole-building airtightness tests provide air leakage rates per unit area that are much higher than the recommended system air leakage rates. This is because a large proportion of the leakage is through elements other than the insulated portion of the building envelope. Specifying whole-building airtightness testing in commissioning procedures may encourage designers and builders to pay attention to airtightness details, but the results cannot be directly related to the system requirements identified in the NBC.

[7] CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*. Canadian General Standards Board, Ottawa, 1986.

[8] CGSB-149.15 (under development), *Determination of the Overall Envelope Airtightness of Buildings by the Fan Depressurization Method Using the Building's Air Handling Systems*. Canadian General Standards Board, Ottawa, 1996.

6. AIR BARRIER SYSTEMS IN TYPICAL INSULATED-WALL DESIGNS

6.1 Air Barrier Systems and Approaches to Provide Protection from Precipitation

Wall construction can be broken down into two fundamental types: face-sealed systems and rainscreen wall systems.

6.1.1 Face-Sealed Wall Systems

In face-sealed systems, the weather barrier and air barrier systems are both placed on the outside surface of the wall. Some stucco walls, precast concrete panel wall systems, and exterior insulation and finish systems (EIFS) use this design concept.

6.1.2 Rainscreen Wall Systems

Common Type. Rainscreen wall systems are more common in Canada than face-sealed systems. In these systems, there is a drainage element or space inside an exterior cladding. The cladding acts as a rain and weather screen, but the design accepts that some water will pass through the screen. The drainage element or space may act as a capillary break and provide a place for water to drain by gravity to the base of the wall where it can drain to the exterior. The air barrier system can be anywhere on the inner side of this drainage element or space. In the following section, rainscreen cavity wall systems are classified by the location (inside or outside) of the air barrier with respect to the structural wall components. This classification is based on practical issues because of similarities and differences in detailing, rather than functional, requirements.

Pressure-Equalized Rainscreen Wall Systems. There is one special type of rainscreen wall that warrants special mention and that is the pressure-equalized rainscreen (PER) wall system. In it, the drainage space is divided vertically and horizontally into compartments and vented to the exterior. When a wind gust creates a change in pressure outside the cladding, air flows through the vents into the cavity to maintain the pressure across the cladding, near zero, at all times. By minimizing the driving pressure difference across the cladding, water entry through or around the cladding is also minimized. To summarize briefly, some rules of thumb about the design of PER wall systems are:

- The air barrier system must be much tighter than the vented cladding of the rainscreen.
- Recent research at NRC has indicated that the air leakage levels recommended by the NBC for air barrier systems and required in the CCMC *Technical Guide* are appropriate. PER wall performance is relatively insensitive to further air-tightening.

  The drainage space must be divided into compartments, especially near corners. If air from a high-pressure region can flow laterally through the space as well as around corners to a low-pressure region, pressure equalization cannot occur. Compartment seals between the air barrier and the cladding must be provided to stop this type of air flow. Significant research is still necessary to determine the size of the vent for the compartment.

  When PER design principles are being applied, the methods of providing the compartment seals must be considered. Creating a seal between the cladding and an air barrier system that is inside structural elements may be more difficult than with an air barrier outside the structure. PER wall performance depends on the ratio of cladding vent area to free volume of the cavity.
- The free volume of a drainage space in a PER wall system is the volume of connected air space bounded by the cladding, the air barrier, and the compartment seals. Solid materials and

closed-cell foam insulations take up volume, reducing the connected air space. Most fibrous insulations can be considered part of the connected air space.

The air barrier system should be rigid. If the air barrier system displaces air under pressure, more air will have to flow into the air space to equalize pressure, increasing the time to pressure equalization. In the PER systems, air barrier systems that are rigid or fully supported in both directions by rigid materials are preferred.

6.2 State-of-the-Art Details

With the greater understanding of loads on air barriers and the development of new materials, detailing of air barrier systems has changed. Designers must be in a position to assist the trades by providing drawings and specifications showing how a continuous, structurally supported air barrier system is constructed. In the main field of an opaque wall, the air barrier system is generally fairly simple. Designs must indicate how penetrations through the face of the air barrier are dealt with and how intersections and corners are handled. There are now many sources of information about air barrier detailing. Some demonstrate a better understanding of the principles of air barrier systems than others. The following sources may be drawn on after careful examination of the principles outlined in this document:

- the manufacturer's literature and design guidelines,
- CMHC Best Practice Guides,
- new home warranty publications,
- trade association publications, and
- proceedings of conferences.

Almost all these sources provide two-dimensional illustrations of air barrier systems showing continuity at laps, joints and connections, structural backing, and location with respect to insulation. These details are generally inadequate when communicating the complex geometry required at transitions where the intended plane of airtightness shifts. Transitions at window to wall and curtainwall to wall, for instance, often require such a change in plane of airtightness. The following section provides conceptual details for some of these transitions.

6.2.1 Face-Sealed Wall Systems

The following details illustrate approaches to face-sealing on precast and EIFS wall systems. Designers and owners should be cautioned that these systems are not only prone to the ingress of water and air as the sealants deteriorate but they also require ongoing maintenance of the face seals.

6.2.2 Rainscreen Wall Systems

Rainscreen wall systems with and without pressure equalization are systems that provide improved performance with respect to both air- and watertightness over the service life of a building.

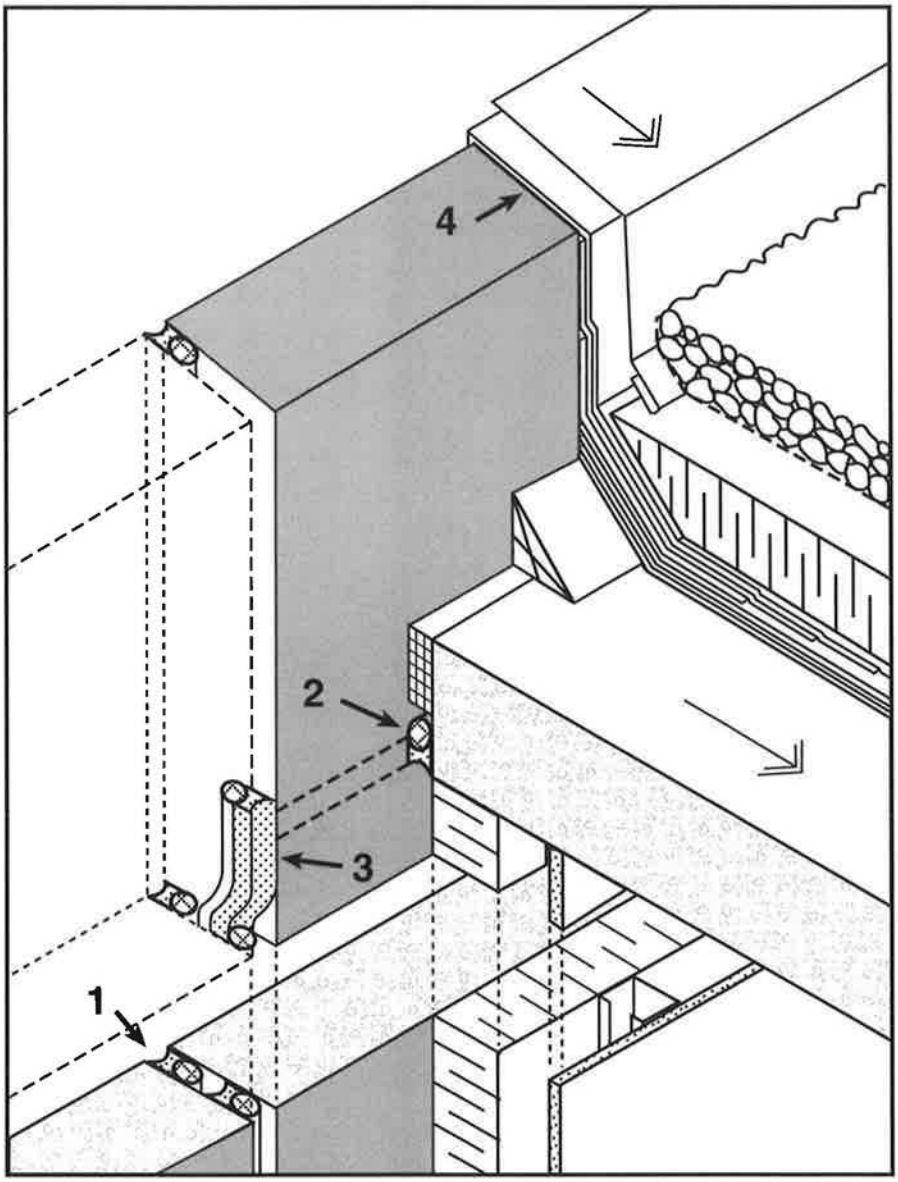


Figure 11. Face-Sealed Precast Wall Panels and Roof Connections

1. 2-stage sealant joint between precast panels.
2. Sealant between precast panels and concrete roof slab.
3. Portion of sealant joint applied from the interior of the building to ensure positive bond with fully compatible horizontal sealant joint at the edge of the roof slab (roof as plane of airtightness).
4. Roofing system to lap and bond to precast concrete parapet.

Note: The shaded area on the drawing represents the designated air barrier system.

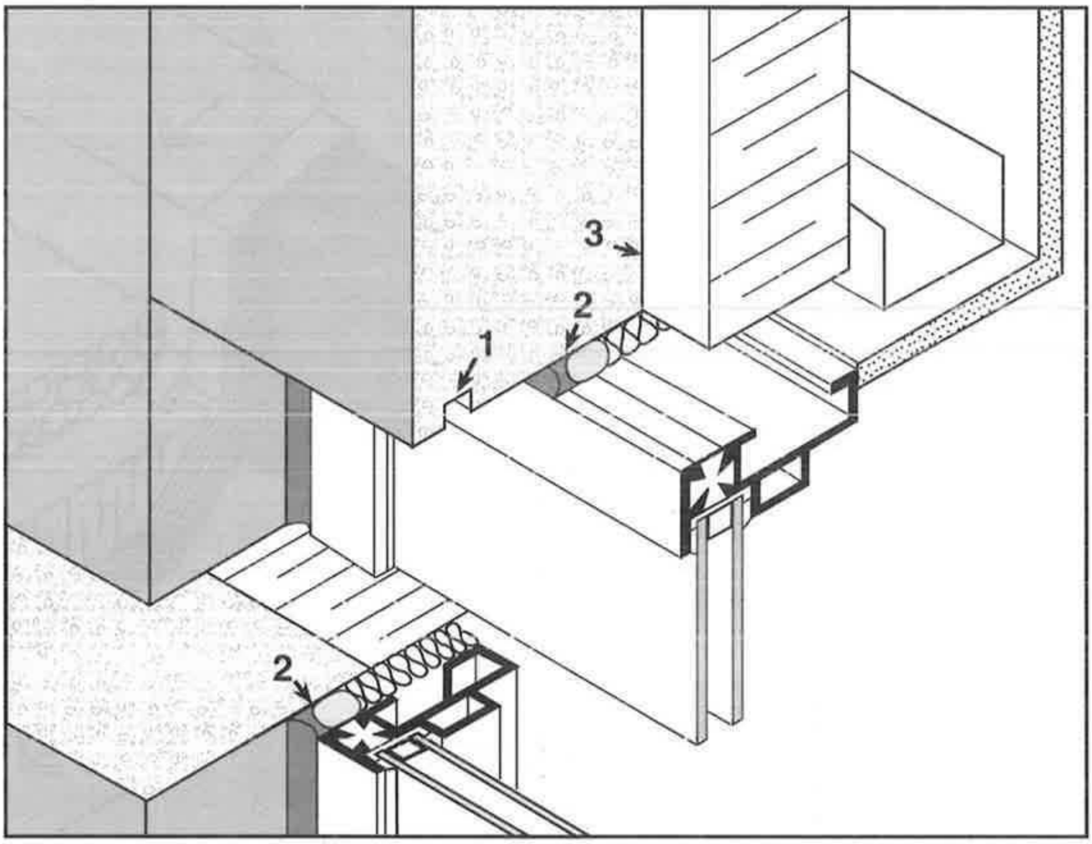


Figure 12. Face-Sealed Precast Concrete Wall, With a Face-Sealed Window, Jamb and Head Connection

1. Drip at top of precast concrete window opening.
2. Sealant and backer rod between window frame and precast panel.
3. Continuous contact between insulation and precast concrete is critical to performance of the insulation system.

Note: The shaded area represents the designated air barrier system.

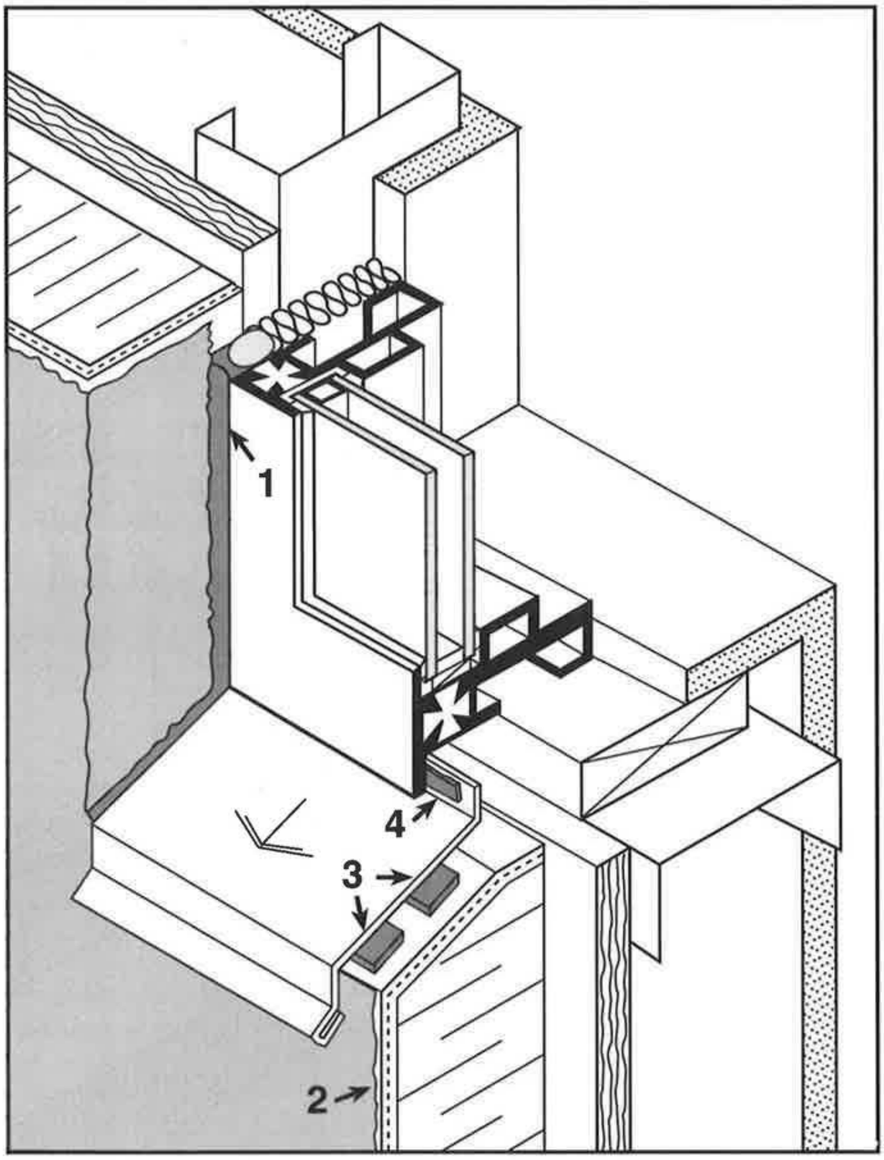


Figure 13. EIFS Wall System, Window Jamb and Sill

1. Sealant bead and backer rod between face-sealed window jamb and EIFS base coat.
2. EIFS base coat and finish coat are intended to form the plane of airtightness of the air barrier system in the opaque portion of the wall.
3. Sealant beads between EIFS base coat and metal sill. (Note that the sill extends beyond the face of the wall.)
4. Sealant bead between window frame and metal sill (to maintain the continuity of the plane of airtightness to the window).

Notes:

(i) EIFS industry details are not resolved industry-wide for all systems and materials.

(ii) The shaded area represents the designated air barrier system.

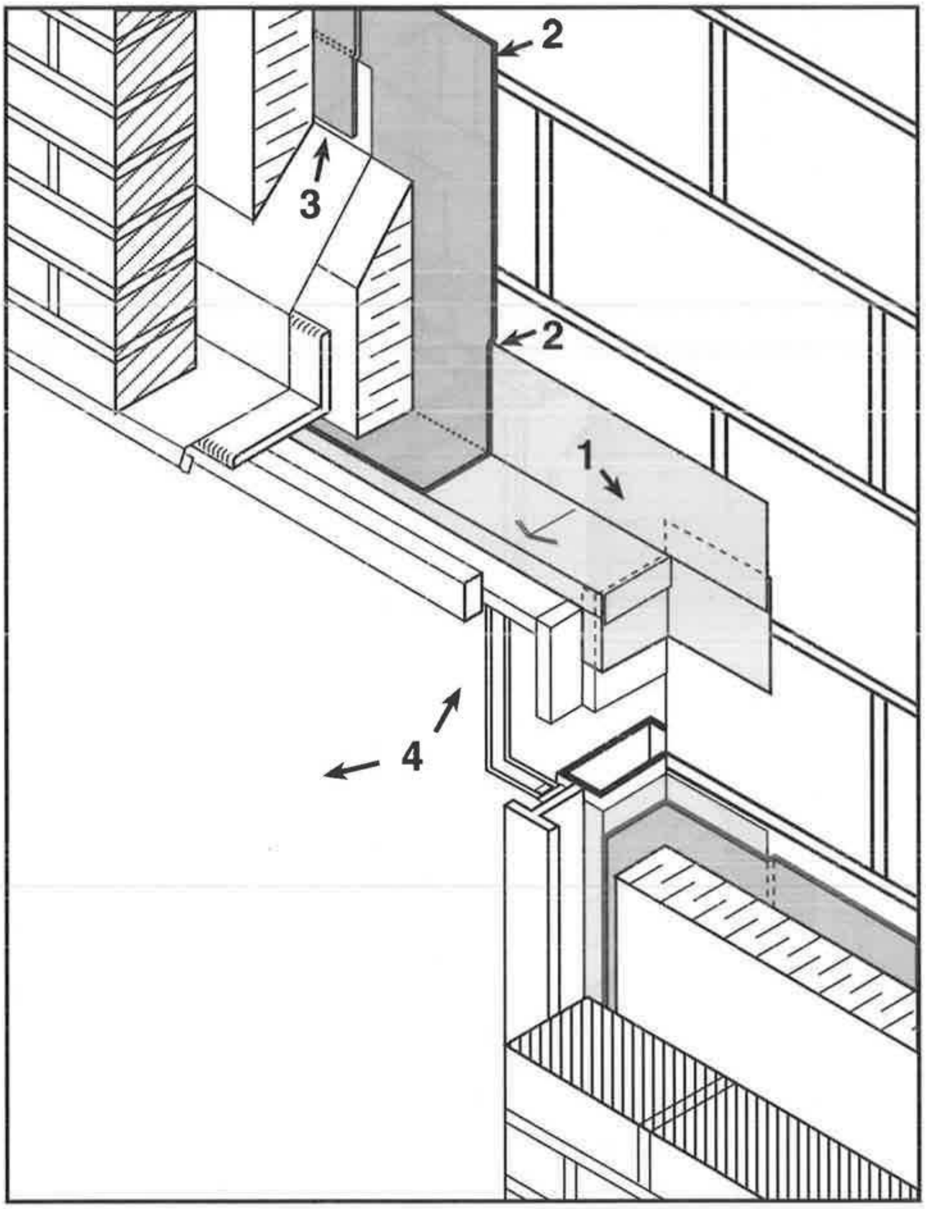


Figure 14. Brick Veneer and Concrete Block Back-Up Rain Screen Wall, Window Head, and Jamb

1. Mechanically fastened sheet metal support (sloped to window frame shoulder) for air barrier membrane.
2. Membrane air barrier fully adhered to concrete block and sheet metal support. Metal support connected to window frames (shown as a curtainwall section) with glazing tape.
3. Through-wall flashing interfaced with air barrier to provide a shingle effect.
4. Sealed Insulated Glass Unit.

Note: The shaded area represents the designated air barrier system.

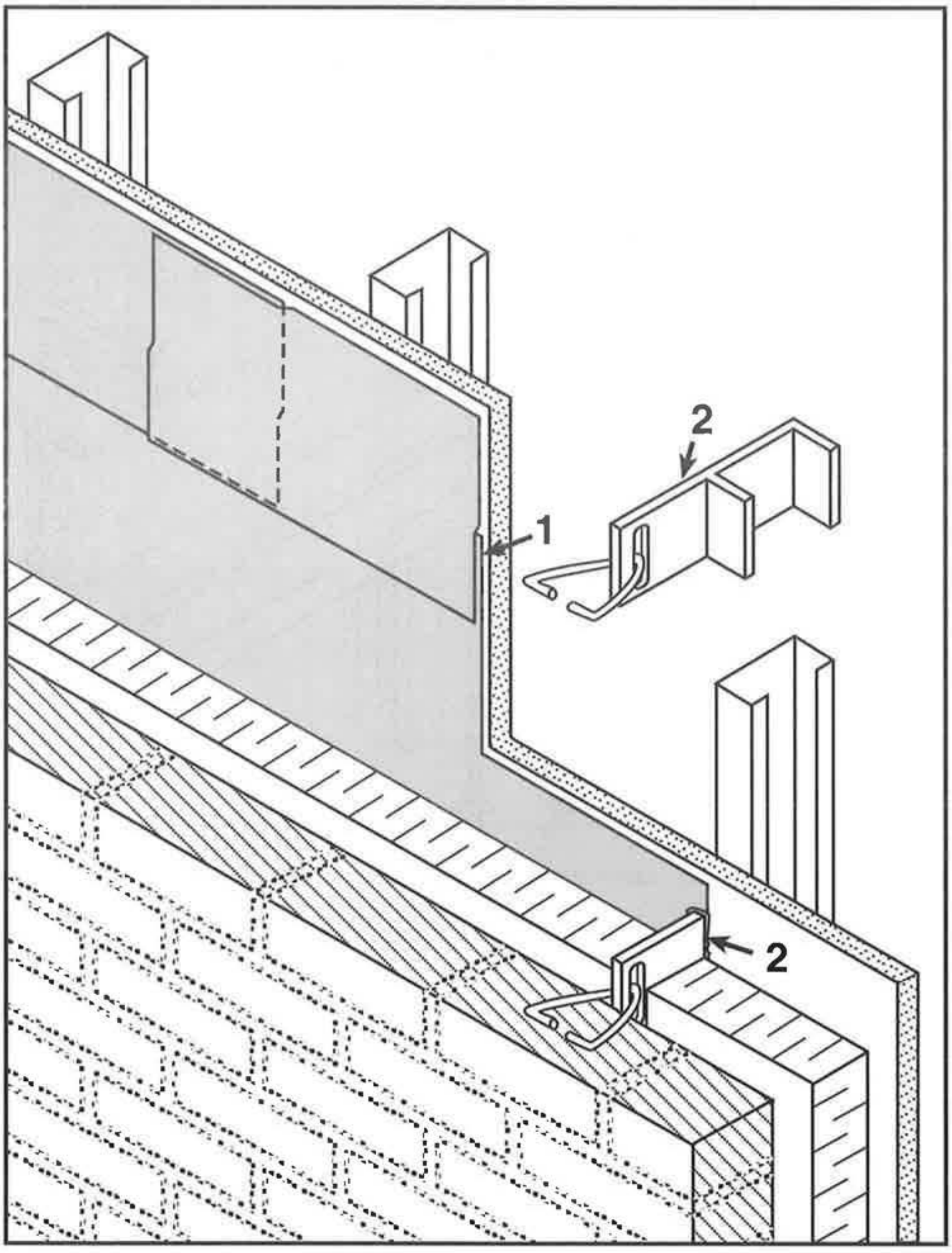


Figure 15. Brick Veneer and Steel Stud Rainscreen Wall with Gypsum Board Sheathing

1. Membrane air barrier lapped to provide shingle effect and fully adhered to gypsum board sheathing.
2. Membrane-compatible sealant required around all masonry ties and any other punctures through the plane of the air barrier.

Note: The shaded area represents the designated air barrier system.

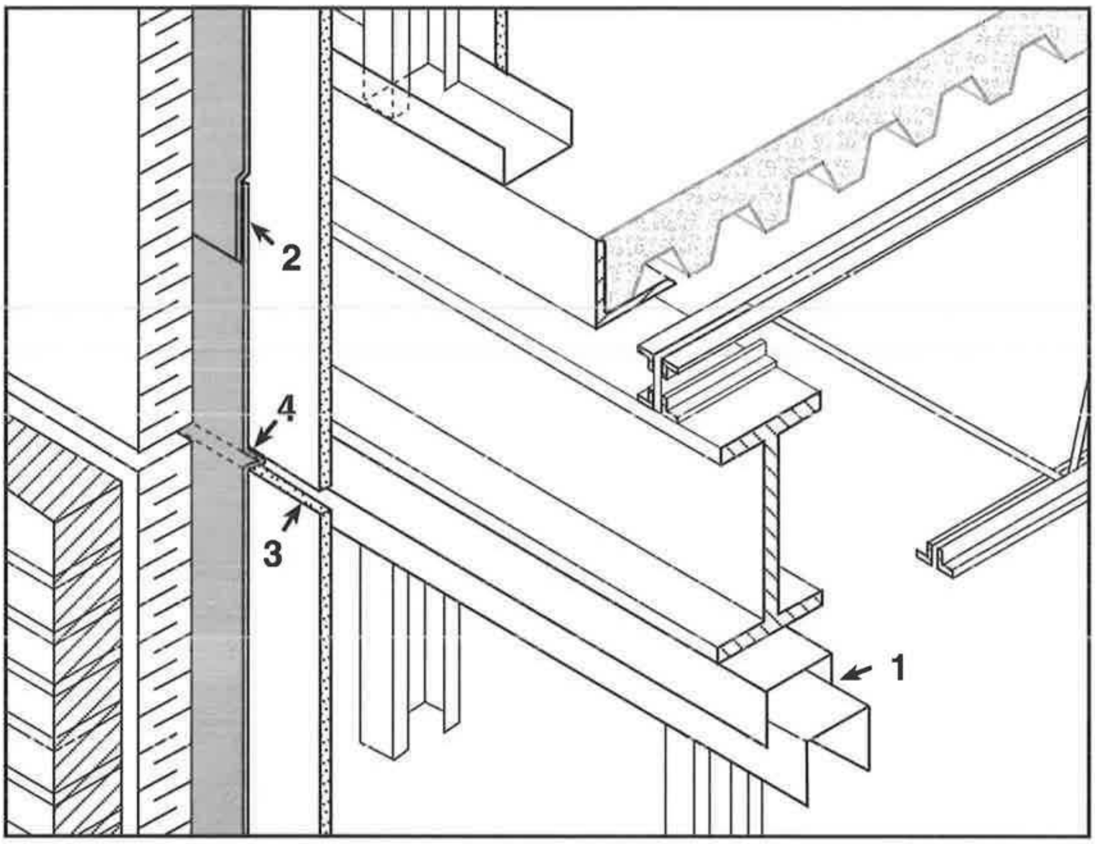


Figure 16. Brick Veneer and Steel-Stud Rainscreen Wall with Gypsum Board Sheathing

1. Steel-stud wall top anchorage must accommodate structural framing deflection.
2. Lapped membrane air barrier fully adhered to gypsum sheathing substrate.
3. Gap in gypsum board sheathing to accommodate structural framing deflection.
4. Loop membrane air barrier to accommodate deflection.

Note: The shaded area represents the designated air barrier system.

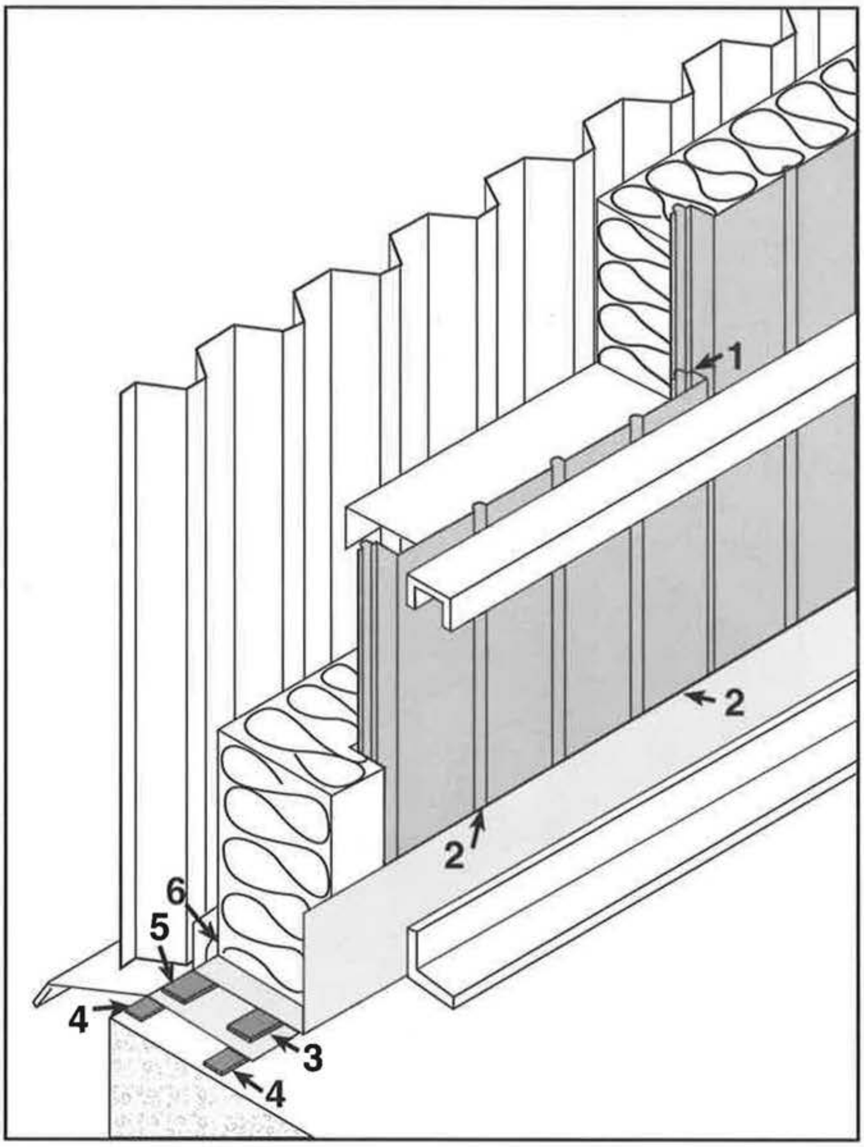


Figure 17. Metal Wall System with Liner Air and Vapour Barrier, Floor Slab Connection

1. Factory- or field-applied sealant required at metal wall liner joints.
2. Sealant and strip of elastomeric membrane air barrier required at the joint between the wall liner and the bottom track.
3. Bead of sealant between bottom track and base flashing.
4. Beads of sealant between base flashing and concrete foundation wall.
5. Bead of sealant at the edge and between bottom track and base flashing.
6. Drain holes at bottom track.

Note: The shaded area represents the designated air barrier system.

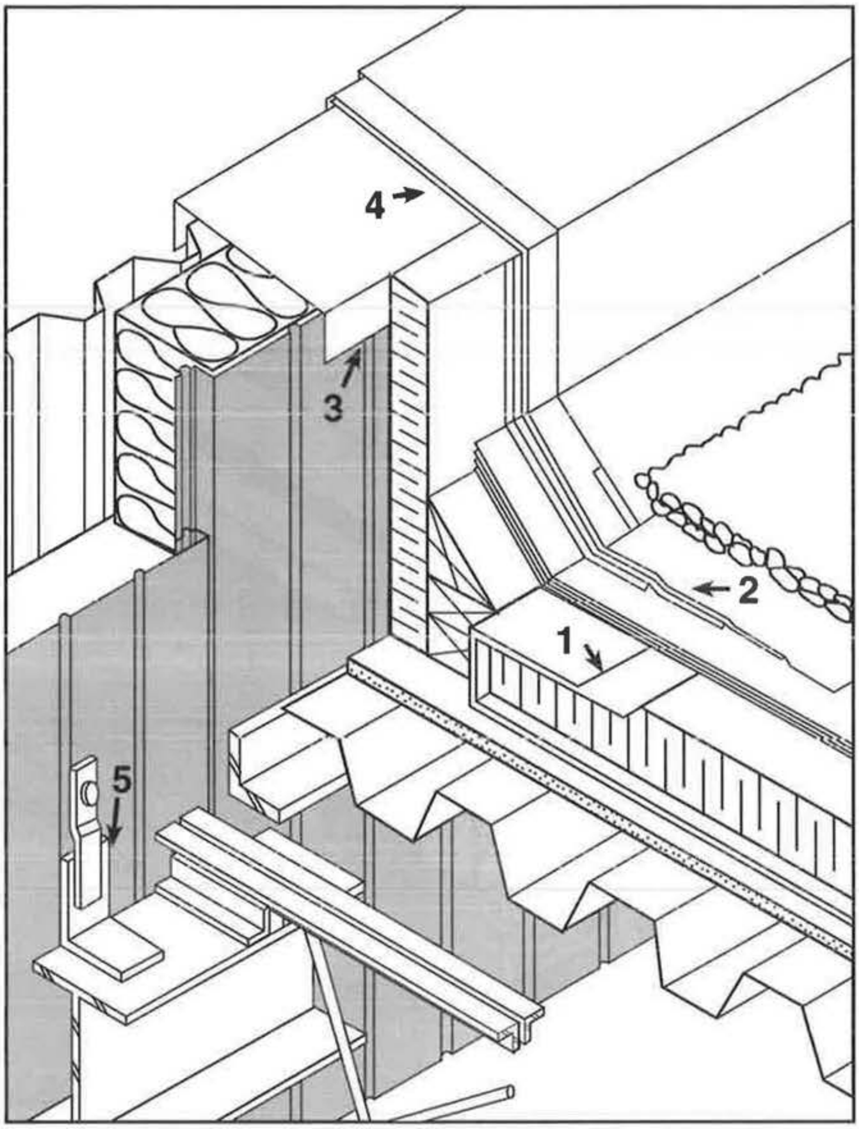


Figure 18. Metal Wall System with Liner Air and Vapour Barrier, Roof Connection

1. 2-ply vapour barrier.
2. 4-ply roofing (plane of airtightness).
3. Sealant and/or strip of membrane air barrier required at connection of liner panels and wall cap.
4. Roofing system fully bonded to wall cap (continuity with plane of airtightness).
5. Slip connection between wall system and steel structure to allow for deflection. Seal at connection through liner.

Note: The shaded area represents the designated air barrier system.

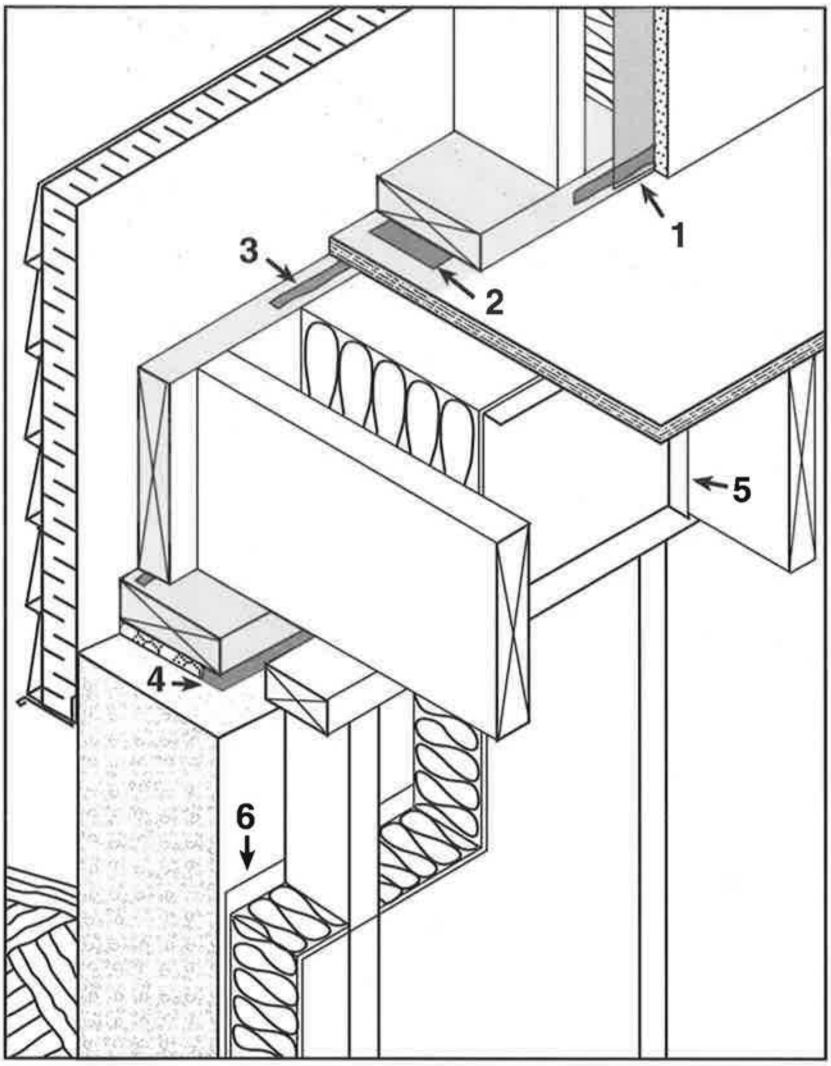


Figure 19. Wood-Frame Wall to Foundation Connection

1. Seal the polyethylene air/vapour barrier to wall plate.
2. Airtight gasket between wall plate and subfloor. Seal subfloor joints.
3. Sealant between subfloor and floor header.
4. Sealant between plate and concrete foundation wall.
5. Lap and fasten polyethylene vapour barrier.
6. Moisture barrier up to level of grade.

Notes:

(i) In this assembly, the polyethylene is used as an air and vapour barrier above the subfloor, and used as a vapour barrier only below the subfloor.

(ii) The shaded area represents the designated air barrier system.

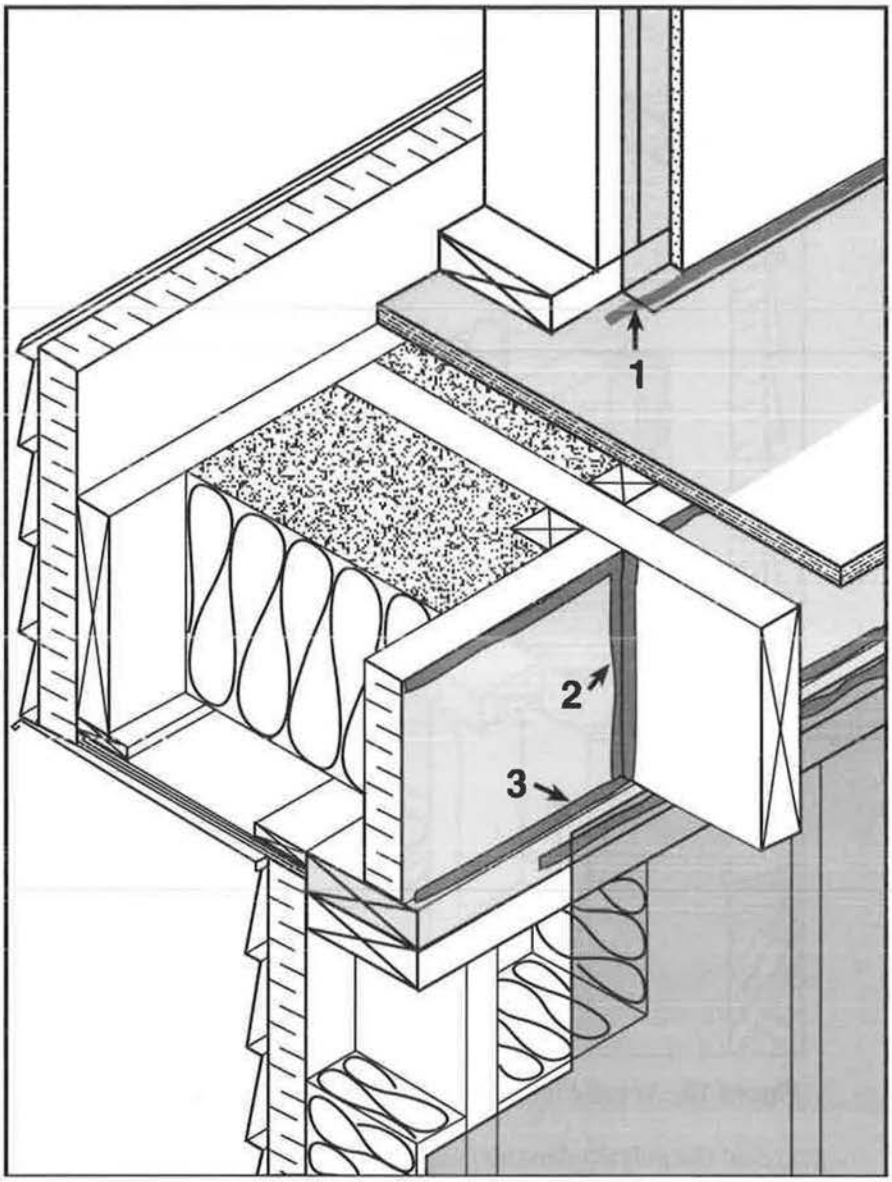


Figure 20. Wood-Frame Floor Overhang

1. Seal polyethylene to subfloor. Seal subfloor joints.
2. Seal all around extruded polystyrene rigid insulation (mechanically attached to wood blocking).
3. Seal polyethylene to polystyrene rigid insulation blocking.

Notes:

(i) In this assembly, the polyethylene is used as both the air barrier and the vapour barrier.

(ii) The shaded area represents the designated air barrier system.

APPENDIX A

EXTENDING LOW-RISE AIR BARRIER CONCEPTS TO HIGH-HUMIDITY AND HIGH-RISE BUILDINGS

The CCMC evaluation methods, requirements and criteria, and much of the related research was specifically targeted to evaluate the performance of air barrier systems for walls of low-rise buildings (three stories or fewer) with normal indoor humidity conditions (up to 35% RH). The principles, however, can be extended to other cases, including higher-humidity conditions, high-rise buildings and other building envelope assemblies. Designers must recognize how these other applications affect the loads and conditions that the air barrier system must resist, and use design methods and details that will best accomplish this.

A-1 Walls for High-Humidity Buildings

In a high-humidity low-rise building, the additional vapour pressure and moisture content of exfiltrating air dramatically increases the potential for condensation-related deterioration. For low-rise buildings, there is no increase either in air pressures or in the structural requirements of the CCMC-specified loadings for an air barrier system.

Reducing the potential for moisture collection requires examining the tightness of the air barrier system, its location with respect to insulation, and the vapour permeance and location of the vapour barrier.

Some information can be drawn directly from the NBC. As shown previously in Table 1, the Appendix to Part 5 recommends that the air barrier systems of high-humidity buildings have a system air-leakage characteristic of less than 0.05 $L/(s \bullet m^2)$ at 75 Pa. Part 9 requires that in a high-humidity application, the vapour barrier must have a vapour permeance of less than 15 $ng/(Pa \bullet s \bullet m^2)$. The data in Table 2, dealing with the proportion of insulation that needs to be outside of a material with low air and vapour permeance, are based on indoor humidity levels typical of houses. When designing for higher-humidity environments, the proportion of insulation to the cold side of the low-permeability material should be increased above the level shown in the table.

Based on the building science principles discussed in Section 5, the location of the air barrier may be more important than additional airtightness.

When designing for a high indoor humidity environment, the simplest method of providing "forgiveness" in the wall system is to use an air barrier system that has most of the 'thermal resistance' on the cold side. As explained in Section 5, the potential for moisture collection falls off rapidly as a higher proportion of the thermal resistance is placed to the outside. Placing the air barrier on the room side of the insulation and ensuring that the surfaces to the outside can "breathe" make use of this fact.

Since most air leakage occurs at junctions with other building assemblies or at penetrations through the air barrier, it is important to avoid as many of these complications as possible and to avoid difficult junctions, such as those that change the plane of the air barrier system through the structure. **An air barrier that is located outside the 'structure' offers the best way of reducing and simplifying connections with other building assemblies, while, as stated above, providing the majority of the insulation on the cold side of the air barrier.**

A-2 Walls for Buildings Greater than Three Stories

The main ways in which high-rise buildings differ from low-rise buildings with regard to air barrier systems can be summarized as follows:

1. Wind pressures on upper stories are higher, imposing higher structural requirements on the air barrier.
2. The long-duration pressures caused by stack effect and mechanical systems are higher.
3. There are generally greater design provisions for expansion and creep of the structure and cladding. Vertical and horizontal expansion joints in the cladding are more common and may require a greater range of movement.
4. There is generally a greater expectation of durability. The need to work at increased heights greatly skews the cost of replacement/expected life ratio of any component in favour of durability. The difficulty of inspection lessens the ability to note the onset of deterioration and the consequence of failure can be higher.
5. There is a greater variety of construction methods and materials likely to be employed. Non-combustible construction is required in contrast to wood-frame construction in many low-rise buildings.
6. The construction process can be more complex, with more participants. Coordinating and sequencing different trades can be more difficult.

Any building higher than three stories must be designed to Part 5 requirements, including an air barrier that must be able to resist and transfer the full wind load to the structure. This should be part of the structural design process. It is worth noting that the increase in assumed wind pressure with height is a function of the exposure factor that increases with height by a factor of

$$\left(\frac{\textit{height in stories}}{10}\right)^{1/5}$$

The design wind pressure of a 30-storey building is about 1.5 to 1.6 times that of a 3-storey building.

The CCMC test protocol provides criteria for two wind climate zones, one where the 10-year wind pressure is less than 0.40 kPa, and the other where it is less than 0.60 kPa. The test protocol includes tests at gust pressures of double these values. **Overbuilding by selecting an air barrier system tested to the more extreme climates may provide comfort that the assembled system can handle higher loads, but does not replace a structural evaluation.**

The increases in long-duration driving pressures are particularly important to consider, because they typically drive more exfiltration and infiltration than wind. This makes them the primary contributor to condensation problems. Stack forces increase in direct proportion to height. At the top of a 30-storey building, the stack force created by exfiltrating pressure can be 10 times that of a 3-storey building, and the air flow through a particular leak will be 3 to 10 times as great.

Again, airtightness is important for avoiding condensation problems, but one of **the most practical methods of providing "forgiveness" for small leaks is to install a substantial proportion of the insulation outside the air barrier.**