Evolution of wall design for controlling rain penetration

Chown, G. A.; Brown, W. C.; Poirier, G. F.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40002861
Construction Technology Update; no. 9, 1997-12

Evolution of Wall Design for Controlling Rain Penetration

Archived Content

Information identified as archived is provided for reference, research or recordkeeping purposes. It is not subject to the Government of Canada Web Standards and has not been altered or updated since it was archived. Please contact us to request a format other than those available.

Construction technology Update No. 9, Dec. 1997

by G.A. Chown, W.C. Brown and G.F. Poirier

The design of walls to control rain penetration has changed considerably over the years. This Update describes the evolution of walls from massive masonry construction through to pressure-equalized curtain-wall assemblies, focusing on developments in rainscreen walls.

The penetration of rainwater through walls depends on the following combination of conditions:

- the presence of water
- openings in the assembly that permit water to enter
- forces that can move water through the assembly.

The control of rainwater penetration depends on being able to control any one or all of these conditions.

Rain penetration creates problems ranging from damage to interior finishes and furnishings, to the growth of mold and mildew, to premature structural deterioration. Over time, rain penetration has been controlled in various ways ranging from massive masonry construction to pressureequalized rainscreen (PER) curtain-wall assemblies.

Single-Element Protection

A variety of constructions have been used that rely essentially on a single element for rain-penetration control. Where the construction material is relatively porous, the wall relies on mass to absorb and re-release the moisture. Solid masonry walls typically depend on this mechanism (see Figure 1). Where the construction material has low porosity (e.g., cast-in-place concrete or masonry walls made of dense stone), the wall may rely on the low water permeance of the material for rain-penetration control. However, this may not be sufficient as any cracks in the wall will allow direct penetration. Traditionally, many of these walls have provided acceptable performance because of the protection afforded by building details that direct water away from the walls. Such details include wide roof overhangs, cornices, and drips on window sills.

Moisture transfer forces

- kinetic energy of raindrops
- surface tension
- capillarity
- gravity
- air-pressure difference

With increased understanding of structural design, and the eventual transition from load-bearing walls to curtain walls, thinner assemblies became possible, making more efficient use of structural material and space. The loss of mass and thickness, however, often led to rain penetration.

Figure 1. Massive masonry construction

Relatively thin, single-wythe walls continue to be used in buildings in milder service environments, or in commercial or industrial buildings that need provide only limited environmental separation. In such situations, buildings can be designed to tolerate some moisture penetration from rainwater without adversely affecting the building fabric, the health or safety of the occupants, the intended use of the space, or the operation of building services.

Face-Sealed Walls

Face-sealed walls rely on single-element protection and require the exterior surface of the wall to be essentially impermeable to water and air. Because these walls are insulated on the interior of the sealed surface, the surface is exposed to extreme changes in temperature and solar radiation, both of which impose large stresses on the joints between cladding components, and on the junctions between the cladding and other components. The durability of sealants under these conditions is significantly less than in more protected environments, and is also considerably less than that of other components in the cladding assembly. Without timely maintenance and replacement of the sealant, the walls lose their water and air tightness, which can affect the performance of all their intended functions. Because of its relatively low initial cost, the face-sealed approach continues to be used. To sustain performance, however, significant resources must be allocated for on-going maintenance.[1]

Multiple-Element Protection

The preferred approach for rain-penetration control is to design multiple-element protection into a wall. Many assemblies incorporate more than one element to control rain penetration. Historically, such elements include an air space or drainage plane and a water-resistant layer as well as joint and junction details that also incorporate multiple elements of protection. Such features have been observed in both masonry and wood-frame constructions.

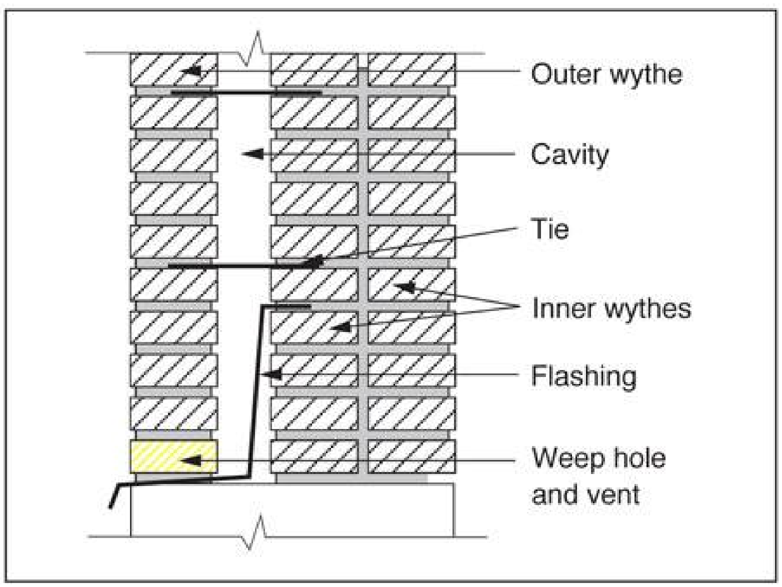

Figure 2. Drained and vented cavity wall

Cavity Walls

The masonry cavity wall evolved in response to a need to control rain penetration through masonry walls that had become thinner. It is defined as "a construction of masonry units laid with a cavity between the wythes. The wythes are tied together with metal ties or bonding units and are relied upon to act together in resisting lateral loads."[2] Both the inner and outer wythes, and the bonding units or ties, have structural functions beyond self-support under gravity. The cavity prevents water from reaching the inner wythe by means of capillary action; it also allows water to dissipate through the capillary action of the outer wythe during dry spells.

The drainage of cavity walls was advocated in the early 1900s, although it was not common practice at the time.[3] Today, however, it is a well-known fact that when drainage holes and flashing are provided at the bottom of the cavity (as required by the National Building Code since 1953), any water that penetrates the outer wythe is able to drain back to the outside (see Figure 2).[4],[5],[6] The drain holes may in some cases also act as vents, allowing vapour in the cavity to dissipate. Although the drained cavity wall can provide considerable protection against water ingress caused by capillarity, surface tension and gravity, this type of assembly cannot address water transfer due to air-pressure difference without the addition of other elements to the wall.

The current edition of the National Building Code (NBC) requires cavity walls to have a minimum cavity width of 50 mm.[5] This relatively wide cavity helps prevent mortar dropped in the cavity from forming bridges between the outer and inner wythes.

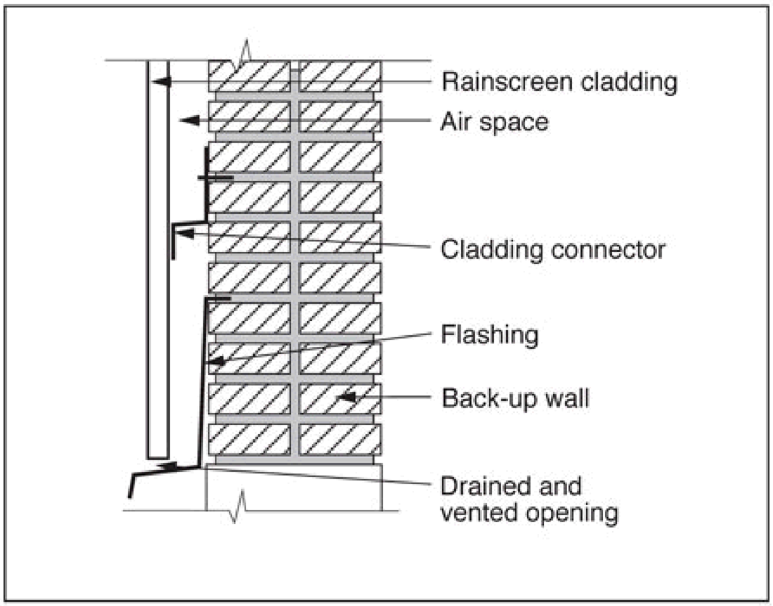

Figure 3. Rainscreen concept applied to solid loadbearing brick wall

Early Wood Constructions

At least as early as 1604 in Canada, walls of buildings that required enhanced protection against rainwater ingress incorporated multiple control elements.[7] By the 1920s, standard wood-frame residential wall assemblies typically consisted of cladding layered over building paper which was, in turn, layered over exterior sheathing. In many cases, an air space between the cladding and the building paper was incorporated into the wall system.

The Rainscreen Principle

The Original Concept

The rainscreen principle, introduced in 1946, was the next refinement of rain- penetration-control strategies for walls.[8] Wall assemblies built according to this principle consisted of a cladding, made of a lightweight, low water-permeance and low water-capacity material, installed on the exterior of a solid load-bearing brick wall, with a drained and vented air space between the cladding and the load-bearing wall. The idea was to reduce the moisture load on the back-up wall and, by providing this space, to permit the removal of moisture transferred from both the exterior and the interior (see Figure 3). When properly detailed, this type of wall prevented water ingress due to raindrop kinetic energy, gravity, capillarity and surface tension. It performed like a drained and vented cavity wall; however, like the cavity wall, it did not explicitly address the issue of air-pressure difference as a driving force for rain penetration.

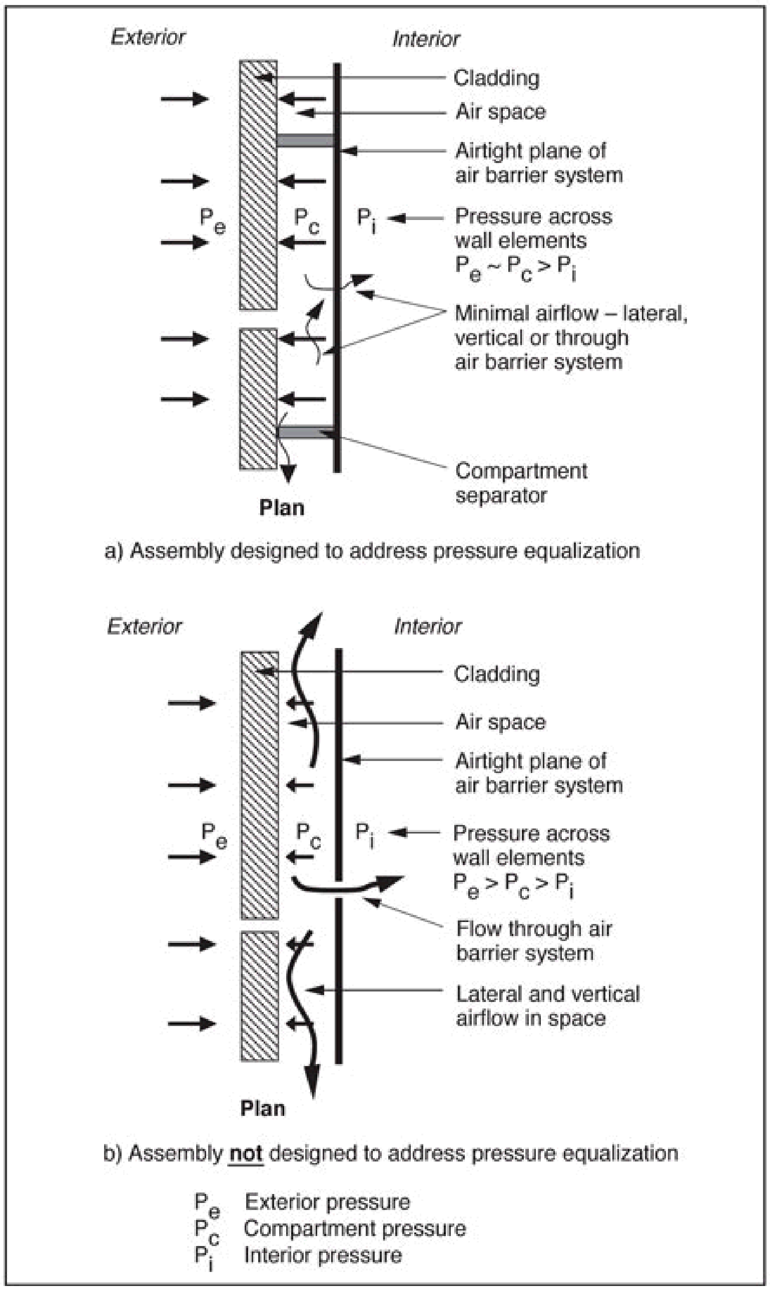

Figure 4. Air flows through and within rainscreen wall assemblies

How much ingress control is needed?

Different wall assemblies can accommodate different amounts of water penetration before damage occurs. The permissible quantity of water depends on the materials used and on the ability of the assembly to dry out. The latter, in turn, is dependent on the configuration of the assembly and on the climate.

Open Rainscreen Walls

The rainscreen concept evolved in the 1960s through the work of the National Research Council's (NRC) Division of Building Research. This further evolution, known as the "open rainscreen wall," addressed all of the forces that can lead to rainwater ingress, including the control of airflow through and within the wall, in order to minimize air-pressure differences across the cladding (see Figure 4).[9] The research demonstrated that by

- adding holes
- controlling the size and distribution of vent holes
- providing an air space
- dividing the air space into compartments, and
- incorporating an air barrier system in the back-up wall

the pressure across the rainscreen assembly can be reduced, thus significantly reducing one of the forces responsible for driving the rain through the wall (see Figure 5). This consideration of pressure equalization across the wall assembly differentiated the open rainscreen wall from its predecessors.

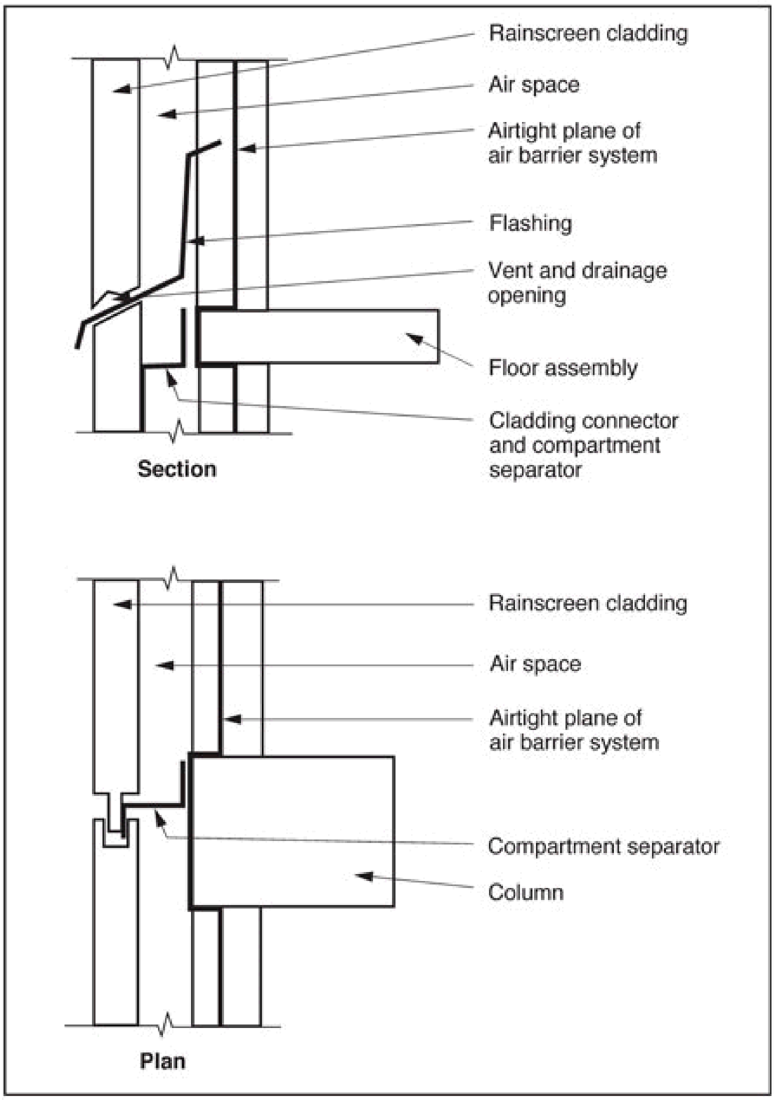

Figure 5. Open rainscreen wall

Current Applications of the Rainscreen Principle

Conventional or Basic Rainscreen Walls
The application of the rainscreen principle that first saw widespread use in the 1970s consists of:

- a cladding (rainscreen)
- a second line of defence, and
- an air barrier system in the back-up wall.

These are considered to be the essential elements of a viable rainscreen wall assembly.

Cladding. The cladding, which is the first line of defence, provides a rain-shedding screen. The rainscreen material is not necessarily lightweight and may or may not have low water permeance or low water capacity. In fact, rainscreen walls with brick veneer cladding are very common. One of the important features of the cladding is that the rainscreen material is assembled so that it minimizes rainwater passage both through and around the cladding.

Joints in the cladding must be detailed to control raindrop kinetic energy, surface tension and gravity. Openings in the rainscreen have an impact on reducing the airpressure difference across the cladding, but pressure equalization has to be addressed in conjunction with the other elements of the wall, particularly the air barrier system. The elements that connect the cladding to the back-up wall should be designed to control moisture transfer by surface tension, capillarity and gravity. Components such as windows and doors that penetrate through the rainscreen, and the junctions between these components and the rainscreen, should also be designed in accordance with the rainscreen principle in order to control moisture transport forces. The incorporation of air spaces that drain to the exterior is one example of this comprehensive approach.

Second line of defence. This comprises a flashed, drained and vented air space, and a material installed on the exterior of the back-up wall to protect moisture- susceptible components (or, in other words, a water-resistant membrane). The role of the second line of defence is to ensure that any water penetration through the cladding will not affect the rest of the wall assembly. For houses and small buildings, the NBC requires a wall assembly to have two layers of sheathing membrane if not supported by sheathing, one layer if supported by sheathing or, alternatively, sheathing that is either not moisture susceptible or that incorporates a sheathing membrane.[5] As with the cladding, the second line of defence should be applied to all components of the wall assembly in order to provide the necessary continuity.

The minimum allowable width of the air space depends on the cladding material and on the material used to create the air space. For brick veneer walls, the minimum width is 25 mm. (It is important to ensure the cavity is kept reasonably clear of mortar.) Where wood furring is used, there must be sufficient material thickness for structural attachment of the cladding: the NBC calls for 19 mm for wood furring installed in houses and small buildings.[5] In any case, the width should not be less than 10 mm to allow for variations in construction.

Adequate performance is provided in many low-rise residential assemblies clad with materials such as stucco, or vinyl, metal or wood siding, even though the air space is less than the generally accepted minimum width and may be discontinuous between flashing levels. These assemblies reflect a long tradition of wood-frame construction with multiple protective elements. The first level of protection is provided by the cladding system which, when properly designed, greatly limits the moisture load on the second line of defence. In addition, roof overhangs may be used to limit the quantity of rainwater on the cladding. Because these assemblies have reduced drainage capacity, the sheathing membrane, or other material installed to protect moisture-susceptible materials in the back-up wall, may need to be upgraded to provide greater water resistance and thus ensure an effective second line of defence.

Air barrier system. For most types of buildings, the NBC requires a back-up wall to have an air barrier system, i.e., a continuous barrier for the purpose of controlling airflow through the wall.[5,10]

This also reduces the static air-pressure difference across the cladding. The air barrier system allows the rainscreen cladding and the second line of defence to perform effectively.

When is a rainscreen wall no longer a rainscreen wall?

The original rainscreen wall consisted of a lightweight protective cladding installed on the outside of a drained and vented air space on the exterior of a structural wall. In many of today's wall assemblies, the cladding may not be lightweight, and the drained and vented air space may not exist, but a second line of defence against rain ingress is provided. Such walls are considered to be rainscreen walls.

Modifications to the Basic Rainscreen Wall

As wall designs, construction methods, and building materials have developed, the application of the basic rainscreen wall concept (as described above) has been modified to respond to different service environments, durability requirements and (construction) cost constraints. Whenever a modification is made, the overall performance of the assembly must be assessed to ensure that the individual components and the assembly as a whole are capable of handling the water to which they will be exposed in their service environments over their design service lives.

Recently, the construction industry has been experimenting with assemblies that incorporate a self-draining material in the air space, providing an alternative to the combination of a simple air space and a protective membrane as the second line of defence. These materials include semirigid glass fibre panels with oriented fibres and self-furring materials such as profiled plastic sheet. Assemblies that have incorporated these materials are sometimes referred to as "drainscreen" walls. Many recent building envelope failures have occurred because they were designed with very limited or no drainage capacity behind the cladding. In these cases, an inadequate assessment of the water resistance required in the second line of defence has led to the premature deterioration of the wall as a consequence of the moisture load imposed on it. A wall design that works well in one climate may not perform adequately in another because of differences in the intensity and frequency of rainfall, average relative humidity and temperature, and wetting and drying cycles.

Pressure-equalized rainscreen walls are the most sophisticated version of the rainscreen wall.[11] In these assemblies, the openings in the rainscreen are specifically designed to allow both static and dynamic pressure equalization to take place across the rainscreen. The number and geometry of the vent holes are determined on the basis of allowing sufficient air to flow in and out of the air space quickly enough to respond to wind gusts so that the pressure difference across the cladding and within the compartments of the air space can be minimized, thus reducing the rain-driving force. The effective area of the vent holes depends on the airtightness of the air barrier system, on the stiffness of the rainscreen and of the air barrier system, and on the volume of the individual compartments that make up the air space. The air space behind the cladding is divided into separate drained and vented compartments to control vertical and lateral airflow within it. Since air pressure induced by wind varies over the height and width of the building, the size of the compartments, which are designed to minimize the difference in air pressure within each compartment, varies over the face of the wall. Compartments must be closed at all corners of the building to prevent the wind from affecting the wind pressures on adjacent building faces.

Guidelines for the Design of Rainscreen Walls

Both conventional and modified rainscreen walls have become the norm for low-rise residential construction. Consequently, numerous publications provide information on their design and construction.[12,13,14] However, design guidelines currently available for PER walls are very limited and do not sufficiently deal with the issue of controlling rain penetration under wind-driven conditions.[15,16]

Summary

Over time, the rainscreen principle for wall design has evolved and a number of variations have been developed. The performance of these assemblies depends on:

- the materials and construction details used
- the moisture loading on the wall
- the drying forces in the service environment.

Virtually any assembly can provide acceptable performance under certain conditions; however, where an assembly varies from the conventional rainscreen, a careful assessment must be made to ensure that it can handle the moisture to which it will be exposed.

Ms. G.A. Chown *is a senior technical advisor with the Canadian Codes Centre of the National Research Council's Institute for Research in Construction (IRC).*

Mr. W.C. Brown *is a senior research officer with the Building Envelope and Structure Program of IRC.*

Mr. G.F. Poirier *is an evaluation officer with the Canadian Construction Materials Centre of IRC.*

References

1. Retrofit Strategies for Face Sealed Metal and Glass Curtain Walls. Public Works and Government Services Canada, Ottawa, 1995.

2. CAN3-A371-M94 – Masonry Construction for Buildings. Canadian Standards Association, Etobicoke, 1994.

3. ICS Reference Library: Common Brickwork. International Textbook Company. Scranton, PA, 1909.

4. National Building Code of Canada 1953. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1953.

5. National Building Code of Canada 1995. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1995.

6. Ritchie, T. Cavity Walls. CBD 21, Division of Building Research, National Research Council of Canada, Ottawa, 1961.

7. Ritchie, T. Canada Builds 1867-1967. National Research Council of Canada, Ottawa, 1967.

8. Johansson, C.H. The Influence of Moisture on the Heat Conductance for Brick. Byggmastaren, Nr., 1946.

9. Garden, G.K. Rain Penetration and Its Control.CBD 40, Division of Building Research, National Research Council of Canada, Ottawa, 1963.

10. Building Science Insight '86. An Air Barrier for the Building Envelope . Institute for Research in Construction, National Research Council of Canada, Ottawa, 1989.

11. Brown, W.C., Rousseau, M.Z. and Dalgliesh, W.A. Field Testing of Pressure-Equalized Rainscreen Walls. ASTM STP 1034, 1991.

12. Builders' Manual. Canadian Home Builders' Association, Ottawa, 1994.

13. Construction Principles to Inhibit Moisture Accumulation in Walls of New Wood-Frame Housing in Atlantic Canada. Canada Mortgage and Housing Corporation, Ottawa, 1985.

14. Siding Problems. Builders' Series, Canada Mortgage and Housing Corporation, Ottawa, 1988.

15. Baskaran, A. Review of Design Guidelines for Pressure Equalized Rainscreen Walls. Internal Report No. 629, Institute for Research in Construction, National Research Council of Canada, Ottawa, 1992.

16. Poirier, G.F. and Brown, W.C. Pressure Equalization and the Control of Rainwater Penetration under Dynamic Wind Loading. Construction Canada, Vol. 36, No. 2, 1994.

National Research Council of Canada
December 1997
ISSN 1206-1220