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THE BRICK-VENEER SCREENED WALL

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ABSTRACT

A number of publications have been produced and circulated that make design recommendations for the so-called pressure-equalized rainscreen (PER) portion of brick veneer wall systems. While these recommendations are not necessarily consistent or comprehensive, they do provide a set of consensus guidelines for design. This paper critically assesses the relevance to brick veneer wall systems of three of these documents. It is concluded that as-built brick veneer wall systems rarely, if ever, reach and maintain pressure equalization of wind affects across the screen.

INTRODUCTION

The use of a single-wythe brickwork veneer (BV) as cladding for exterior walls is common especially on residential buildings. In Ontario, for a variety of reasons, there have been some problems with the performance of brick veneer wall systems especially on multi-unit residential buildings. Many, if not most, of these problems involve moisture.

Rain is, of course, a major source of moisture and in order to control rain penetration the screen approach is favoured. This approach acknowledges that some rain water will inevitably penetrate the single-wythe of brickwork. It follows that both drying and drainage must be facilitated but, in order to reduce the amount of rainwater that enters and is transferred across the brickwork, it is advantageous to attempt to reduce or even eliminate the air pressure difference across the brick veneer screen. This is the basis for the so-called pressure-equalized rainscreen (PER) approach to wall design.

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In theory, the PER approach will ensure that when the wind blows there will be an instantaneous equalization of air pressure across the screen. By eliminating the air pressure differential across the screen one of the motive forces for the transfer of water inwards is eliminated. Theoretically, the benefits of the PER approach to wall design are:

- one (and only one) of the motive forces for rain penetration, air pressure inwards, is eliminated
- even when it is not raining, if the wall is very wet the elimination of an air pressure difference across the screen may be advantageous
- the lateral wind load imposed on the screen and its lateral connections by the wind will be affected, possibly reduced, and in some wall systems reduced significantly.

Over the last few years there have been a number of publications on PER wall systems. In Canada, agencies such as CMHC and IRC/NRCC have devoted considerable funds and effort to addressing the issues involved in PER performance. Three recent publications are particularly relevant, namely:

Review of Design Guidelines for Pressure Equalized Rainscreen Walls by A. Baskaran, Internal IRC/NRCC Report No. 629, March 1992, and repeated in summary form in the *Canadian Consulting Engineer*, March/April 1993. While the report was merely a review and not intended for general distribution, the document did provide design information, and some of this information was given wide distribution in the later publication.

Facts and Fictions of Rain Screen Walls by M.Z. Rousseau, published by IRC/NRCC as a Construction Practice Note. This note has been widely circulated and was also published in *Construction Canada.*

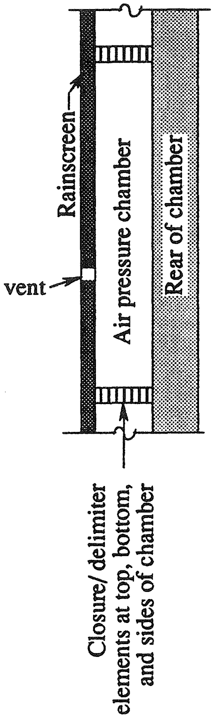
Brick Masonry Rain Screen Walls, August 1994, Technical Note No. 27 (revised), issued by the Brick Institute of America (BIA). This document is particularly important because it is an official trade publication with wide circulation.

These three publications are not research reports, nor do they provide any new information. They do, however, collectively promote a set of consensus recommendations for the so-called PER portion of a wall system and therefore need to be carefully examined, particularly from a brickwork standpoint.

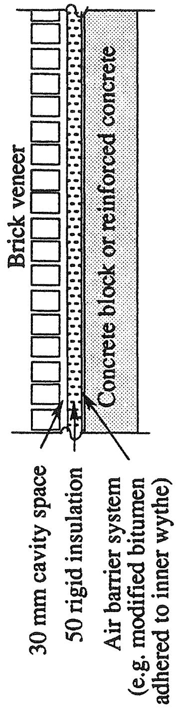
The objective of this paper is to critically assess some of the implications of these recent guidelines for masonry veneer wall systems. The emphasis is on the design recommendations and not on the background research or the reasoning behind them. Moreover, each of the publications acknowledges that work remains to be done and that caution is needed in applying the guidelines.

REVIEW OF DESIGN GUIDELINES

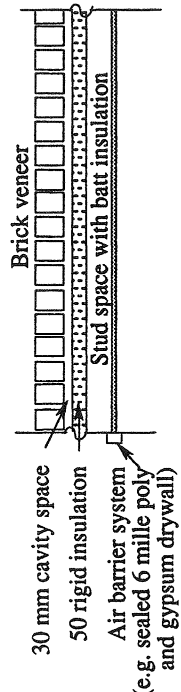
Figure 1 shows vertical sections through two typical brick veneer wall systems, as well as the idealization usually used to illustrate the so-called pressure equalized rainscreen



1A:
Primary Components of an Idealized Pressure Equalized Rainscreen Wall System



1B:
Insulated Brick Veneer / Concrete Block Wall System



1C:
Insulated Brick Veneer / Wood or Steel Stud Framing Wall System

Fig. 1: Representative Wall Systems

portion of the wall system. The primary components of the PER portion are shown in Figure 1A . The consensus guidelines are discussed and categorized under the headings that follow.

Chamber or Compartment Size (b_C, h_C, d_C)

At the perimeter of each face of the building—i.e., within 6 m (20 ft) of the corners and the top and within 3 m (10 ft) of the ground or over the entire width of the whole first floor—the breadth of any chamber should not exceed 1.2 m (4 ft).

Height recommendations are not as clear cut. Baskaran implies a limit of 1.2 m (4 ft) in both directions. Alternatively, the height should not exceed 6 m (two floors). Over the remainder of each face it is recommended that the breadth range between 3 m and 6 m with a limiting height of 6 m. The BIA document goes a little further and also recommends that the area (b_c x h_c) of chambers inside the perimeter region be limited to the following:

- For design wind pressures of less than 718 Pa (15 psf), $A \leq 37$ m^2 (400 ft^2)
- For design wind pressures of between 718 Pa and 1200 Pa (25 psf), $A \leq 23$ m^2 (250 ft^2)
- For design wind pressures of more than 1200 Pa (25 psf), $A \leq 9$ m^2 (100 ft^2).

These values are reasonably comparable to chambers with dimensions of 6m x 6m (36 m^2), 3m x 6 m (18 m^2) and 3m x 3m (9 m^2) respectively.

The depth (d_c) of the chamber should be greater than 25 mm (1") according to IRC/NRCC, or greater than 50 mm (2") according to the BIA publication. Baskaran also identifies an upper limit on depth, i.e., $d_c \leq 10 \times \sqrt{A_v} \div A$, where A_v and A are the venting and chamber wall areas respectively.

For a wall with a brick veneer screen, it should not be too difficult to meet these dimensional requirements. For instance, vertical support is usually provided at each floor level or, at most, every two floors for the veneer and, consequently, the height limit is readily satisfied. Breadth criteria can be met by attempting to provide vertical closure at or close to the following locations:

- vertical control joints in the veneer
- corners, i.e., not only at the perimeter of the building face but also at all significant changes in facade direction
- at windows, doors, and other major openings.

These are all logical and appropriate places for airtight and, usually, watertight vertical separation quite apart from any need to achieve instantaneous pressure equalization.

As far as the depth of chamber is concerned, the 25 mm provision will be met by current design practice with regard to cavity requirements. This presumes, of course, that the veneer is built without excessive mortar dams, mortar droppings, or violation of normal tolerances. The BIA requirement for a cavity at least 50 mm deep can also be met but at some additional cost. On the other hand, meeting this requirement does make the cavity less vulnerable to blockage or obstruction.

The question of chamber depth is relatively straightforward provided that the chamber and the cavity or capillary break behind the screen are essentially one and the same thing.

Consider the three walls shown in Figure 1. In the idealized wall (1A), the chamber is apparently a compartment wholly within the cavity. This is essentially the case in a double-wythe masonry wall (1B). However, in the wall shown in Figure 1C the air barrier system is—by design—well inside the cavity and, unless there is a second air barrier, the depth of the chamber extends across the stud space. It follows that the terms chamber and cavity are not synonymous and that the issue of compartmentalization is often somewhat more complicated than sub-dividing the cavity. It also follows that the volume of the chamber will, in such a wall, typically be three to four times that of the cavity.

Chamber Deformability
As mentioned previously, the effectiveness (speed and extent) of any moderation of pressure across the screen depends on the volume of air to be moved into or out of the chamber. The volume of air involved is small. The chamber volume is relatively small, and the air is essentially incompressible. Varying the air pressure in the chamber requires only a small quantity (a slug) of air to be moved into or out of the chamber. Two related considerations are thus air tightness and the stiffness (or, inversely, the flexibility) of the chamber. Obviously, the stiffer or less flexible the chamber, the better.

Insofar as controlling moisture is concerned, it can for all practical purposes be assumed that the brick veneer is deformationally rigid; note that in a structural sense this assumption may not be true. Because there will usually be steep vertical and horizontal pressure gradients, it cannot be assumed that the pressure within two adjacent chambers is equal. It follows that the closure elements should not only be stiff but should also be firmly fixed in position. Stiff and strong horizontal closure is usually provided by support conditions at each, or every alternate, floor. It is more difficult to provide similar vertical closures.

The sixth side of the chamber—the rear—poses the main challenge. The first and most obvious provision is to avoid any fabric-type layer that is not fully and firmly adhered to a stiff substrate. The second provision is to ensure that the rear portion of the chamber is relatively stiff. Bear in mind that the air barrier system may be subjected to the full air pressure (it must if instantaneous pressure equalization is to occur). However, any layers or materials located outside the air barrier system that resist airflow may also experience wind-induced pressures, even if only for short periods of time. The rear of the chamber must be stiff under both pressurization and depressurization, which means that if more than one layer of airtightness is involved, then the nature of their interconnection will be significant.

Of particular concern is the use of housewrap, or any other lightweight fabric, that is not fully adhered to the surface of the rear face of the chamber. In tests on full-scale brick-veneer wall systems (Trow Consulting Engineers, 1993) we observed the ballooning of housewrap under negative pressure—so much so that the material touched the brick veneer and imposed load onto the brickwork. Instead of the ties being in compression under suction, some ties were forced into tension. Under these conditions, the structurally composite interaction of the brick veneer, ties, air barrier and framing can become very complicated. It is thus good practice to use a fabric or lightweight material only if it is either fully and well adhered to a stiff substrate or sandwiched between two stiff layers. If it is not held in place, the material will flap, loosen, and eventually deteriorate or tear.

Quantification—target values for stiffness, flexibility or deformability—has still to be addressed by the industry, but two points need to be emphasized with regard to brick veneer. First, steel stud framing if used, is relatively flexible (compared to concrete block for example). Second, because the brick veneer is connected to the framing by brick ties, the brick veneer must always be engaged in contributing to the resistance of the wind load.

This structural coupling occurs in spite of the fact that the screen pressure may be fully equalized. Wind is, of course, a dynamic rather than a static phenomenon and, for this and other reasons, the nature of structural interaction is fairly complex. Nevertheless, the ties and the brick veneer will always participate in resisting the lateral wind load. It is difficult to model this interaction structurally. Accordingly, when a relatively stiff screen such as a brick veneer is used with a less stiff structural backup, then there is probably little merit in attempting to design either the brick veneer or the ties for a load less than the prescribed quasi-static design loads.

Chamber Airtightness

The air chamber has six sides. The screen is vented: after all, the screen "air leakage" is the means whereby air moves into and out of the chamber. Ideally the remaining five faces of the chamber should be perfectly airtight.

If it is assumed that the top, bottom, and sides of the chamber are perfectly sealed or perfectly pressure equalized between chambers, the issue of chamber airtightness can be reduced to that of the airtightness of the rear wall. The rear wall is also the dominant area. It is probably for these reasons that the IRC/NRCC publications focus on the airtightness of the "air barrier system" in the wall. The BIA does the same, but it refers to this part of the chamber as the "air retarder." This is the first time we have seen the term *retarder* being used in connection with an air barrier but it may be better than the decision by IRC to use the term *barrier* as a divisible or relative standard.

Because it is difficult to build a perfect air barrier, the consensus recommendations for the air barrier system are as follows:

1. A maximum leakage area equivalent to 0.5% of the total wall area may be tolerated.

2. The leakage area should be less than 2.5 to 4% of the venting area (conversely, the vent area should be greater than 25 to 40 times the equivalent air leakage of the air barrier).

3. Since the air barrier system has to sustain the air pressure levels within the chamber, it is further recommended that the air barrier be designed to accommodate the total external wind loading. To deal with extreme pressure gradients, it is also recommended that closure elements in the chamber be designed to take loads two to three times the maximum external wind load.

Looking at the first recommendation from the perspective of brick veneer construction, it would appear that for a representative 1.2 m wide x 2.5 m high section of wall ($A = 3\ m^2$) the maximum tolerable leakage area is 15 000 mm^2 (0.5% of 3.0 m^2). This is equivalent to a single 100 mm x 150 mm hole in the air barrier system, which is on the high side for a 1.2 m length of wall. If, however, it is presumed that over a 1.2 m length there are four open head joints (two at the top, two at the bottom at 600 mm spacing) so that the venting area is equal to 2400 mm^2 ($A_v = 4 \cdot 10 \cdot 60$) then, in accordance with the second recommendation, 2.5% of this area gives a maximum equivalent leakage area of 60 mm^2 or 20 mm^2 / m^2 of chamber wall area.

This latter provision is much more stringent and much more difficult to attain. For instance, a recent survey of walls on apartment buildings conducted for CMHC (Gulay et al. 1993) found that the equivalent air leakage area ranged from about 100 to almost 2000 mm^2 / m^2; even the tightest wall system tested was five times the 20 mm^2 / m^2 calculated above for a typical brick veneer wall.

Consider the first two guidelines in relation to practice. The current NBCC calls for an effective air barrier in all external walls, but it does not quantify effectiveness or address the issue of structural stiffness. The PER guidelines require that the air barrier be designed to resist the total external wind loading, to be airtight, and also to be structurally stiff.

Ideally, a perfect air barrier system should be provided. Practically, this is difficult to realize and an effective air barrier is a more realistic target. Various attempts have been made to quantify the necessary effectiveness. Bearing in mind that any measure of air barrier effectiveness should ideally be a function of climate, type of building, operating conditions, etc., some target values that have been identified are between 0.05 and 0.20 $l/s/m^2$ at 75 Pa (CCMC 1994)—i.e., equivalent to a leakage area of about 8 to 30 mm^2 / m^2.

In many residential wall systems (see Figure 1C), the primary air barrier system (by practice and design) comprises sealed 6 mil polyethylene sheet attached to the inside face of the framing and sandwiched between the interior gypsum drywall and the batt insulation. This primary air barrier is some distance from the rear face of the cavity and is separated from the cavity by a relatively large studspace. If there is only one effective air barrier system, then the stud space and all intermediate layers are also an integral part of the PER chamber.

This raises at least three questions:

- Should a flappable material (polyethylene sheet under suction) be used?
- What about the existence of other secondary layers of air flow resistance?
- How stiff should the intermediate layers be?

The rear wall of the chamber extends to the air barrier system which may include the studspace and exterior sheathing. There may, therefore, be two air cavities between the brick veneer screen and the primary air barrier. These two cavity spaces are coupled with respect to air pressure. The exterior sheathing may very well severely restrict air flow (e.g., extruded polystyrene, gypsum board, etc.). The nature of the coupling and the implications for PER response are complicated. Much depends on the location, the stiffness, and the air tightness of any secondary air barriers. While the secondary air barrier may not be as airtight as the primary air barrier system, it may restrict flow enough to affect the speed and amount of moderation of pressure across the screen.

Venting
A vent is essentially an intentional opening to permit air flow in and out. Various recommendations are made as to the amount, size, and location of venting required through the screen to the chamber.

- *Location and number*. The IRC consensus is that all vents should be placed at the same height and at the bottom of the chamber to permit drainage and also to prevent air flow through the chamber. On the other hand, the BIA note states that "The openings should be positioned at the top and bottom of each compartment. All openings should be placed at the same height respectively to avoid air flow loops in the cavity."

  Earlier it was believed that there should be only one vent precisely to avoid air flow in one vent and out of another. Presumably the IRC/NRC recommendation of a single horizontal row of vents per chamber is based on the belief that the horizontal pressure gradient is generally less steep than that in the vertical direction.

- *Size*. A minimum dimension of 10 mm is favoured to prevent the formation of a water film (due to surface tension or surface drainage) that would block or reduce the effectiveness of air movement. On the other hand, the vent should not be too large or positioned so that it acts as a channel for water entry; this might defeat the main purpose of the exercise.

- *Area*. The vent area recommended depends on the volume, stiffness and the air tightness of the chamber. Nonetheless, Baskaran recommends that "an optimum venting area (A_V) of 1 to 2% of the wall area is necessary to obtain around 75% pressure equalization."

There are problems with this last recommendation. The first is semantic: it is not possible to have a fraction of equalization. The pressure difference may be moderated or modified by 75%, but the screen pressure is either equalized or it is not. Equalization, like integrity, is not a divisible term. The second problem is practicability.

Consider any attempt to apply this provision to a real situation. For example, a 1.2 m wide x 2.5 m high chamber ($A = 3\ m^2$) will require a vent area of at least $0.03\ m^2$ or $30\,000\ mm^2$. For a minimum vent width of 10 mm (equivalent to an open mortar joint) and a brick height of 60 mm, a total of 50 open head joints would be required. All head joints in the bottom 8 courses would have to be left open. The recommendation is impractical for many wall systems, let alone for one with a brick veneer screen.

The BIA document suggests that open head joints spaced at 600 mm on centre horizontally top and bottom are adequate to achieve pressure equalization (i.e., 100 % screen pressure moderation). The result would be equivalent to a vent area of 0.08 % of the wall area. This advice contradicts Baskaran's. Furthermore, the BIA claim that good common practice actually ensures pressure equalization should be regarded as wishful thinking. It must be acknowledged that the BIA has lots of company in making claims of this sort.

PRACTICAL REALITIES

It is difficult to be definitive about what constitutes prevailing common practice. Brick veneer is used on low-rise, single-family residential buildings; medium to high-rise multi-unit residential buildings; and many light industrial and commercial buildings. The quality of design, workmanship, inspection, and materials differ. Nonetheless, of the PER guidelines considered, the following are probably not being met in most buildings:

- *Chamber size*, particularly breadth (bc) recommendations. We wish that we knew of more buildings where vertical closure was being properly provided, at least at all corners. At this time the industry has still to develop vertical closure strips that are strong, stiff, cheap, practical and readily available .
- *Venting area of the screen (A_v).* Vents at the base of the brickwork (weepholes) and often at the top are generally provided. These are usually at head joints at intervals of about 400 or 600 mm. A proprietary insert is often used to keep out rain, insects, etc. The BIA guideline largely endorses this practice. This practice, however, virtually guarantees that pressure equalization of wind effects will never occur. One obvious reason is related to the fact that the IRC/NRCC guideline for optimum venting area (1 to 2% of the wall area to obtain 75% moderation of pressure differences) is at least one order of magnitude greater than good practice provides.
- *Chamber stiffness*. Of particular concern is the longer-term performance of loosely attached fabric type materials that have some degree of airflow resistance in one or both directions. In some cases the manner in which housewrap, building paper, polyethylene is being used is cause for concern.
- *Air barrier system*. The issue is not really airtightness but relative leakiness. For instance, the screen venting area should be some 25 to 40 times leakier than the air barrier. Other related issues involve the situation where the primary air barrier system is inside the face of the studspace. The chamber volume is relatively large, there are two coupled air spaces, and there may even be a secondary (possibly unintentional) air barrier. These issues are not really addressed in the guidelines.

The guidelines are clearly not consistent, nor are they comprehensive. We also know that they are likely to change as a result of work currently being conducted. Nonetheless, a significant effort would be needed for the building industry to move to meet the intent, if not the actual content, of these guidelines. Until then it is highly unlikely that any brick veneer walls will be built that could be correctly classified as PER wall systems. Some degree of screen pressure moderation is as much as could be expected.

SEMANTICS

Terminology is clearly a problem. Table 1 categorizes the primary components of a PER wall, namely the screen, chamber, and vent. Consider the following.

- *Screen.* The screen, brick veneer or otherwise, is much more than a rainscreen, and there is no reason to focus exclusively on the one-function rainscreen label.
- *Chamber.* The nature and extent of the chamber has to be clearly established, especially in those wall systems where the air barrier system is located at or close to the interior of the wall system. Baffling, obstructions, and other aspects of airflow need to be considered. The compartmentalization and composition of the lateral closures and the rear or inner wall of the chamber are a great deal more complex than currently implied.
- *Cavity.* The term cavity is not interchangeable with chamber. It should be reserved for the capillary break behind the screen even if it is filled with an insulating material that allows air and moisture flow.
- *Barrier.* Some consensus needs to be reached about the use of this term in particular, as well as possible alternatives such as retarder, filter, screen, etc. It is appropriate to acknowledge that a perfect barrier (to air or water or water vapour flow) may not be realized. However, continued use of this word to represent all levels of imperfection between 0 and 100% can cause confusion.
- *Pressure Moderation.* In reality, instantaneous pressure equalization of air pressure across the screen is an ideal. There are several reasons why the term *pressure moderation* is to be preferred.
    - It is a more accurate term. Instantaneous pressure equalization rarely occurs and, if it did occur, it would affect only a small portion of the wall area of a building. Wind is a dynamic, stochastic, directional and highly variable phenomenon. Pressure gradients are such that, even if all the appropriate guidelines could be satisfied, widespread and continuous equalization is impossible even on the windward face. Performance in the field, especially at low wind speeds, is actually very different from that simulated in the laboratory or by computers.
    - It would not promote complacency, wishful thinking, false advertising, etc.
    - Equalization is an absolute; moderation is not.
- *Pressure Moderated Screen (PMS).* This term is preferred to *pressure equalized rainscreen* for reasons that should be readily apparent.

Table 1: Components and Characteristics of the Screened Pressure Moderating Portion of an Exterior Wall System

Component	Loading	Primary Physical Characteristics
Screen	Moisture - vapour - water* - ice/snow Solar radiation Thermal - temperature - energy - fire Chemical- acid rain, etc. Wind - air pressure - particulate matter - hail Life Forms - people - animals - insects - micro-biological	Material (s) Surface (Treatment) Dimensions Stiffness (Flexibility)* Permeability - air - water vapour - water * Water flow characteristics (both faces) Moisture storage properties
Vent (s)	Air * Water Vapour Water * Ice/Snow Insects, etc.	Dimensions Shape Number (per chamber) Location (and distribution) Air flow properties Vent area (effective area per chamber)*
Chamber	Air* Water vapour Frost/ice Temperature	Dimensions* Shape Deformability* Airtightness* Air flow properties Obstructions - deliberate (ties, anchors) - accidental (mortar dams) Location (on building) Orientation (wind, rain) Moisture storage properties Water flow properties Drainage capability

* These characteristics are particularly pertinent to this paper.

CONCLUSIONS

The following general conclusions can be drawn.

It is highly unlikely that there are any buildings in North America with brick-veneer-clad exterior walls that perform as pressure equalized rainscreens. Rain may be screened but instantaneous pressure equalization of wind effects rarely, if ever, occurs. Varying degrees of pressure moderation will occur; however, our experience (both analytical and field and laboratory testing) suggests that the extent is not particularly significant. The significance is very much dependent on orientation, the nature of the wind and, of course, whether it is raining.

It is not impossible to build a building with a brick veneer wall system that meets most if not all of the consensus guidelines, but it is impractical and rather difficult.

The available guidelines are not consistent, comprehensive, or complete—nor do they claim to be.

Serious consideration needs to be given to some of the issues raised in this paper, if only to avoid confusion and to enhance everyone's understanding of a sub-topic that has yet to be fully understood.

Given the relative importance of drainage, other water penetration forces, and the potential for drying in screened wall systems, it is quite possible that pressure equalization is being given more attention than it warrants. The real objective is to end up with a wall that performs well. There is more to an economically viable brick veneer wall that performs well than the possible reduction of one of the forces moving water across the brick veneer screen.

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