Technical Note No. 6
THE PRINCIPLE OF PRESSURE-EQUALISATION

CENTRE FOR WINDOW AND CLADDING TECHNOLOGY

This Technical Note is one of five on wind loading for the window and cladding industry. The series comprises:

TN 2 Introduction to wind loading on cladding
TN 3 Wind loading on wall cladding and windows of low-rise buildings
TN 4 Issues relating to wind loading on tall buildings
TN 5 Wind tunnel testing
TN 6 Pressure equalisation

Introduction

Water is forced through openings and joints in walls and windows by several mechanisms. Two significant mechanisms are:

1 Pressure difference acting across a sealed or closed joint may force water through;

2 Kinetic energy of air-borne droplets in a fast moving air flow may carry water through an open joint.

The principle of pressure-equalisation is to reduce the pressure difference across a wall and any consequent air flows by creating a pressure on the rear of the joint or opening that matches, as closely as possible, the pressure on the outer face. It offers advantages in terms of:

- Weathertightness (elimination of the most significant leakage mechanisms, achieved without relying on correctly installed sealants);
- Structural requirements (pressure difference across panels less than peak wind pressure);
- Ease of construction (minor imperfections in the size and fit of components are less critical). However, more complicated detailing of openings, and compartmentation is required.

This technical note describes the principle of pressure-equalisation and how it may be achieved in practice. Reference should be also be made to *Standard for walls with ventilated rainscreens* and *Standard for testing ventilated rainscreens* (CWCT, 1998).

Cladding constructions

Cladding that is designed and constructed on the principle of pressure-equalisation comprises:

1 An outer rainscreen, which intercepts raindrops and drains them safely away, contains large, shielded openings and transfers the wind load to the framing members, and thence the backing wall or building frame;

2 An inner air-tight barrier, which carries wind loading;

3 A cavity between, which is pressurised and provides a means of collecting and draining to the outside any water which penetrates the rainscreen.

Traditional cladding

The rainscreen or two-stage approach to weathertightness is not new; for many years walls have been constructed by hanging a ‘rainscreen’ of vertical tiles in front of a structural wall (Figure 1). In this case the ‘rainscreen’ provides the major barrier to

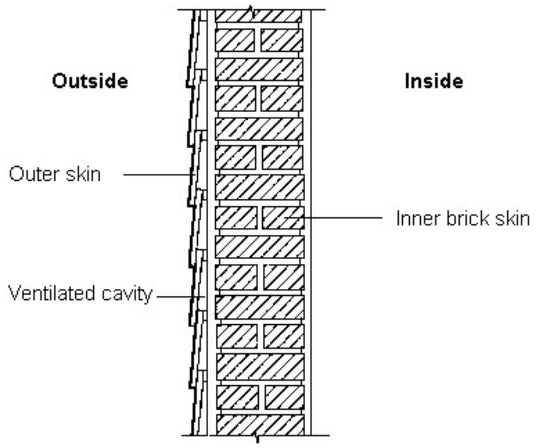

Figure 1 Tile hung wall

water and the brick wall is the structural component and the air barrier. In practice, the effective air barrier is probably the inner, plastered finish to the wall.

Although the tiled screen is very permeable to air because of the large number of gaps between the tiles, little air penetration occurs because the cavity has a limited capacity to accept air and air cannot move through the air-tight barrier behind. This prevents the first mechanism of water penetration (see Introduction above); the second is minimised by the overlapping joints between the tiles. The effectiveness could be further improved by properly sealing the top, bottom and sides of the air cavity (but allowing any water to drain out at the bottom).

A similar consideration applies to the use of tiled roofs where the roofing felt beneath the tiles acts to stop gross air flow between the tiles.

Modern rainscreen facades

Modern rainscreen facades (Figure 2) are designed to be either drained-and-ventilated or pressure-equalised.

Drained-and-ventilated walls have openings to allow any water that passes the rainscreen and enters the cavity to drain out. The drainage openings also allow air to enter the cavity and any change in external pressure on the rainscreen will lead to some change of pressure in the cavity.

Pressure-equalisation is a development of the more traditional drained-and-ventilated cladding systems. Pressure-equalised walls have larger openings. In addition to allowing drainage these openings permit a greater movement of air so that the pressure within the cavity undergoes greater and more rapid change.

Clearly, for both forms of wall there is a varying pressure within the cavity which follows the external pressure but never reaches the same peak levels. In fact, the pressures are only equal for an instant when the cavity pressure is a maximum or minimum and the external pressure is rising or falling (as shown later). For this reason it may be more appropriate to talk of pressure-moderation rather than pressure-equalisation.

Nature of the wind

The UK wind loading code BS 6399: Part 2, like other national wind loading codes considers the wind pressure to be constant for the purpose of structural design. In practice the wind pressure varies with time as shown in Figure 3. The wind pressure on the external face of the building varies about a mean value and may go from a minimum value to a maximum value in a period of just 0.1s or less. The analysis of this complex movement of air into and out of a cavity as a result of these pressure variations is possible. However, it is more normal to make working assumptions about the range of pressure that may be experienced in the cavity.

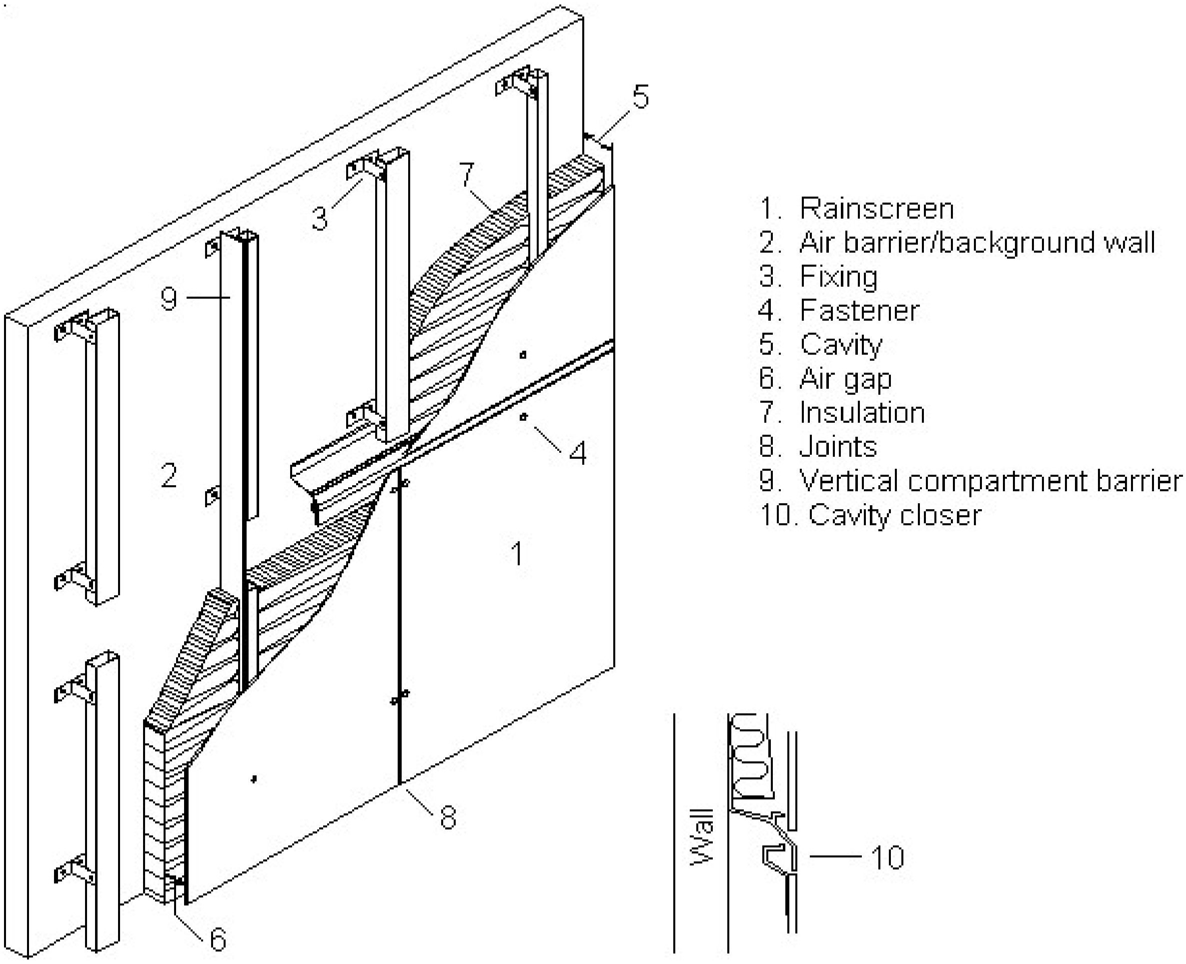

Figure 2 Modern rainscreen facade

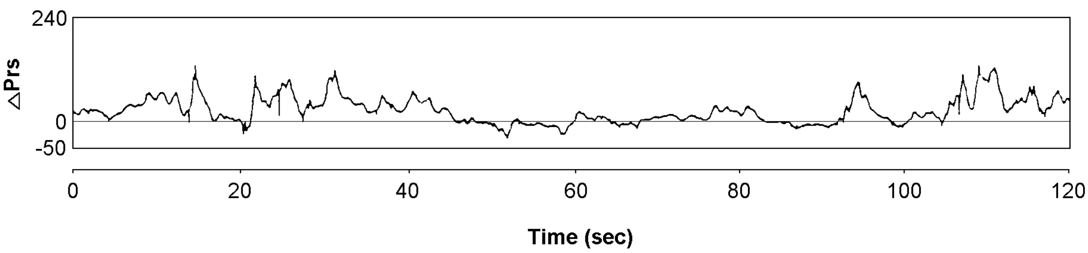

Figure 3 Variation of wind pressure with time

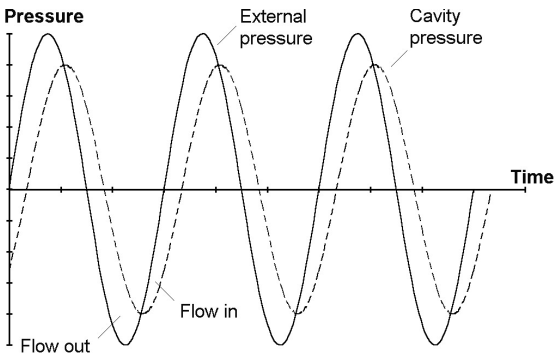

Figure 4 Variation of wind pressure with time

Pressure-moderation

To simplify the explanation of pressure-moderation it is sufficient to consider a sinusoidal variation of wind pressure about a mean value, as shown by the solid line in Figure 4. The pressure in the cavity will rise as the external pressure rises but a pressure difference is needed to drive air into the cavity and the two pressures are never equal. However, when the external pressure starts to fall it will at some point equal the cavity pressure.

At this time the cavity pressure is a maximum and it falls as air is drawn out of the cavity.

Again the two pressures are not equal. This process continues as air is repeatedly drawn into, and expelled from, the cavity. The principle of pressure-equalisation is to make the cavity pressure as nearly equal to the external pressure as possible at any time. In practice there is a degree of pressure-moderation where the pressures are sufficiently close that it is, for the purpose of design, regarded as pressure-equalisation.

Factors determining cavity pressures

The pressures in the cavity will depend on:

1 Air permeability of the rainscreen;

2 Air permeability of the air barrier;

3 Air movement within the cavity;

4 Volume of the cavity;

5 Flexibility of the cavity.

Air permeability

Air permeability of the rainscreen and the air barrier affect the cavity air pressure. The cavity air pressure required for pressure-equalisation will not be achieved if:

- The rainscreen has insufficient area of openings (because air cannot enter the cavity fast enough);
- The other faces of the cavity, principally the air barrier, are too permeable (because air escapes from the cavity).

Considering a sustained and uniform pressure, the pressure difference across an obstruction is given by:

$\delta P = C_d \, \rho \, V^2$

where:

- ρ is the density of air;
- V is the air velocity;
- C_d is a coefficient.

C_d and ρ are the same for both the air and water barriers and it follows that for each, the flow (Q) is:

$Q = A \times V = A \times \delta P^{0.5}$

and that

$A_i^2 (P_c - P_i) = A_o^2 (P_e - P_c)$

where:

- A_i is the area of openings in the air barrier;
- A_o is the area of openings in the rainscreen;
- P_c is the pressure in the cavity;
- P_i is the pressure inside the building;

- P_e is the external pressure on the building.

The degree of pressure-equalisation corresponding to different ratios of rainscreen permeability to air barrier permeability is shown in Table 1.

A wall may be called a pressure-equalised wall if the air permeability of the rainscreen is ten times greater than that of the air barrier.

Rainscreen opening area/ Air barrier opening area	Cavity pressure External pressure
10.0	99.0%
8.0	98.4%
6.0	97.3%
4.0	94.1%
2.0	80.0%

Table 1 Degree of pressure-equalisation for ratios of rainscreen permeability to air barrier permeability

Compartmentalisation

It is important for all forms of rainscreen to place a barrier/cavity closer (items 9/10, Figure 2) at intervals along the cavity to:

1 Minimise air flow within the cavity;

1. Minimise the pressure drop across the rainscreen.

Cavity air movement

Adjacent faces of a building experience positive and negative external wind pressures at the same time and air will be drawn through the cavity at high velocity to low pressure areas if it is non-compartmentalised (Figure 5).

This air flow could move large amounts of water into the cavity, with the risk of water penetration. Therefore, the air cavity must be closed off (at intervals corresponding to the spatial variation and rate of change of wind pressure) to limit air movement, and, moreover, for each cavity to achieve the appropriate cavity pressure (see below).

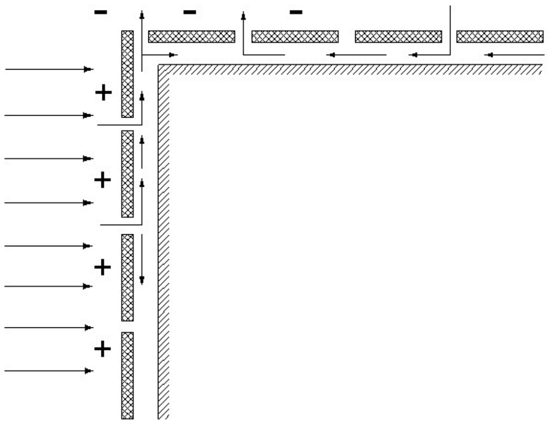

Figure 5 Air flow within a rainscreen cavity at the corner of a building due to

Cavity volume and dimensions

External wind pressures on a building vary in magnitude, from a peak positive pressure at the centre of the windward face caused by stagnation of the wind, to suction of far greater magnitude near the corners of adjacent sides; wind pressures also vary in the vertical direction.

It is important that pressure-equalisation is rapid, since for as long as there is a pressure difference across the joint water can be carried through and into the cavity. Cavity volume has an important effect on the cavity pressures (as do the four other factors of the wall listed above):

- If the cavity compartments are small enough the air pressure within them will be virtually equal to the external wind pressure, preventing water from being drawn through the openings in the rainscreen.
- If the cavity compartments are too large then the time taken to pressurise them will be too great and the cavity pressure shown in Figure 4 will lag too far behind the external pressure. Clearly large openings in the rainscreen will mitigate the effect of cavity volume and the important parameter

is the ratio of cavity volume to vent area in the rainscreen.

Measurements made by the National Research Council of Canada (Ganguli, U & Quiroette, R L, 1987) show the pressure difference (and by inference the degree of pressure-equalisation) achieved for different cavity volumes and vent areas (Table 2). Taking a ratio of cavity volume to vent area less than 80m gives a high degree of pressure-moderation. This is also a prerequisite for a pressure-equalised wall.

Ratio of cavity volume to vent area	Pressure difference across panel	Degree of pressure-equalisation
661m	40-45%	55-60%
459m	28-34%	66-72%
165m	16-22%	78-84%
118m	9-18%	82-91%

Table 2 Degree of pressure-equalisation achieved for different ratios of cavity volume and vent area

To ensure a high degree of pressure-moderation the cavity should be compartmented as follows (Figure 6):

1 At each floor level;

2 At 6.0 m horizontal spacing;

3 At 1.5 m centres within 6.0 m of a corner;

4 At all corners of the building.

Barriers/closers must be of sufficient strength and stiffness to resist the air-pressure differentials which act across them. Particular attention should be given to parapets where the external pressure varies with position and the rainscreen may not have an air barrier behind it. In fact, the rear face of the wall may also be an external surface.

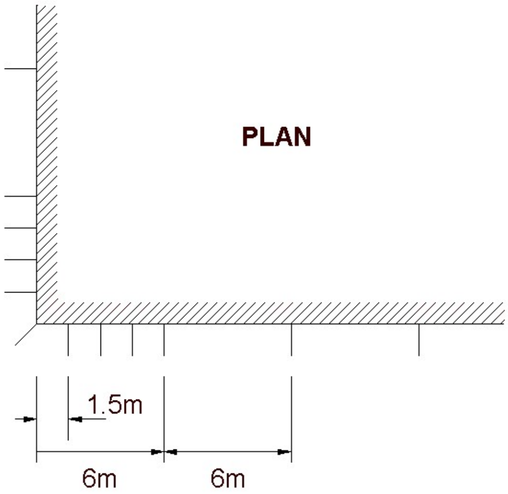

Figure 6 Plan showing horizontal spacing of compartment barriers

Rigidity of the cavity

Rigidity of the cavity (in relation to a flexible member) is not normally a concern. Most forms of construction are sufficiently rigid that the cavity volume does not change more than one or two per cent under wind loading.

The rigidity of the inner barrier affects the time response to pressure-equalisation; as its rigidity increases, less time is required to equalise the wind and cavity pressure.

Pressure-equalised walls

Walls that meet all of the criteria set out above to give high levels of pressure-moderation may be called pressure-equalised walls.

Walls may not necessarily be designed to be pressure-equalised but it is worthwhile applying any of the measures described, in part or as a whole, to produce some moderation of pressure differential and reduce the risk of water penetration.

Structural loading

Walls are conventionally designed to withstand a wind load defined as the difference between the external wind pressure and the pressure inside the building that occurs as a result of infiltration or significant openings in the building envelope.

$P = q(C_{pe} - C_{Pi})$

where:

- P is the loading on the wall;
- q is the design wind loading;
- C_{pe} is the external pressure coefficient;
- C_{pi} is the internal pressure coefficient.

In the case of a wall with ventilated cavities it is not clear what peak pressures act across the air barrier and the rainscreen respectively. In the absence of information it should be assumed that the full wind loading may act on either the air barrier or the rainscreen.

For a pressure-equalised wall it may be assumed that the peak pressure difference across the rainscreen is limited to two-thirds of the peak external pressure, i.e.

$P = 2/3\ q \times C_{Pe}$

However the pressure difference acting across the air barrier should still be taken as the full pressure difference acting across the wall.

Detailed calculation or measurement may well show that the peak pressure difference across the rainscreen is considerably less than two-thirds of the peak external pressure.

Fire stops

Cavity barriers can serve as fire stops to prevent the spread of fire, and vice versa, although this cannot always be assumed to be the case.

Stick curtain walling

The glazing cavity of a stick system curtain wall may be pressure-equalised in the same way as for a window frame. However, it is necessary to compartment the wall just as a rainscreen wall is compartmented.

In the case of a stick wall it may be relatively easy to compartment the wall as the mullions and transoms provide natural barriers to compartment the glazing cavity. For designs where drainage occurs at every glazing or infill cavity it is only necessary to ensure that no air leaks from one glazing cavity around the perimeter of the glass unit/infill panel to the next. This is done by sealing the transoms to the mullions (Figure 7).

A moulded frame gasket (i.e. where the corners are an integral part of the gasket) is recommended for the inner (and outer) seals because of its greater air and water tightness reliability.

For designs where the drainage route is down the mullions, or the drainage routes link different glazing cavities in some other way, it is difficult to achieve effective pressure-equalisation. Such systems are constructed as drained-and-ventilated systems and adequate drainage alone is used to reduce the risk of water penetration.

Pressure-equalised or drained-and-ventilated

The degree of pressure-moderation achieved within a cavity in a glazing frame may be measured under test by using pressure tappings. When measuring cavity and external pressures it is essential that the external pressure varies at a realistic rate. The cavity pressure will always follow the external pressure if the rate of pressure change is slow enough.

Leakage of water and the effectiveness of any drainage can be observed by using an endoscope to see inside the cavity.

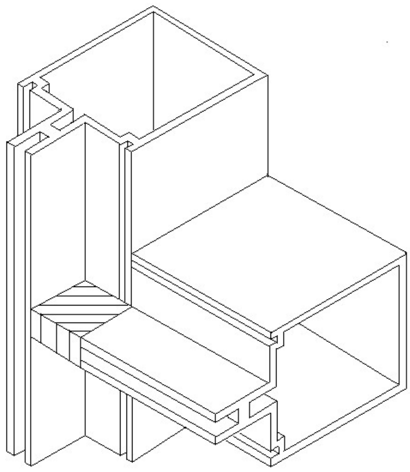

Figure 7 Curtain wall mullion/transom joint closed/sealed off to achieve compartmentation

Glazing frames

Cavities in glazing frames are often ventilated and drained to manage any water that passes the primary outer seals of the frame. Ventilated cavities experience varying cavity pressure and may be designed on the principle of pressure-equalisation.

The cavities in the frame fall into two categories: glazing cavities and the cavities that occur between a fixed framing member and the frame of an opening light (Figure 8). In either case the cavity may be ventilated direct to the front face or it may be ventilated from, and drain through, another drained-and-ventilated cavity.

The presence of ventilation openings in the cavity mean the only barrier against air leakage into the building is the inner glazing gasket, or the inner seal at a parting frame. These seals have to be effective to prevent unacceptable air leakage into the building and achieve a high degree of pressure-moderation. In addition, openings must be of sufficient size to rapidly allow air into the cavity, and possibly an adjacent cavity.

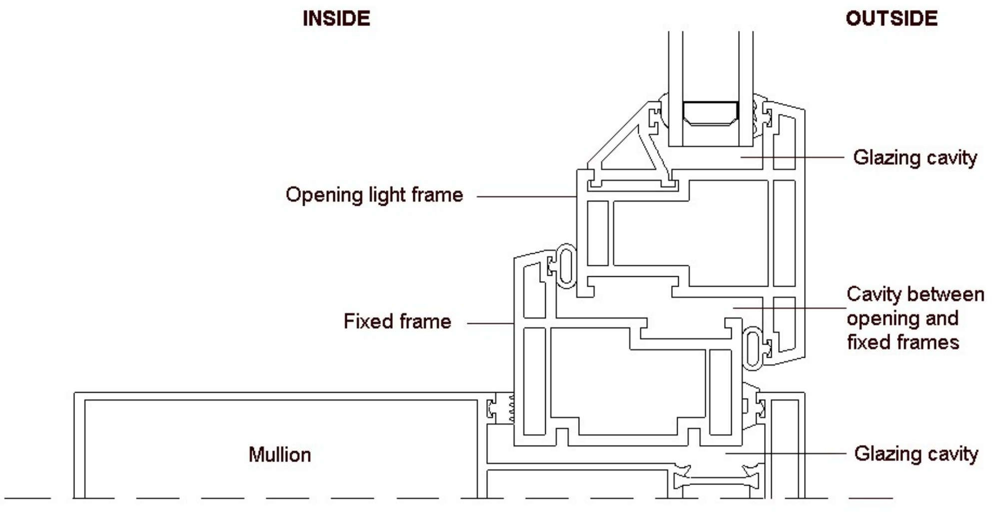

Figure 8 Horizontal section (plan) through a curtain walling frame (mullion with glazed in outward opening window) showing cavities

With window frames the cavity volume is small and the vents do not have to be very large to achieve effective pressure-equalisation. Of more importance with glazing frames is the positioning of the vent openings within the frame. Openings are positioned at the bottom of the frame to provide a drainage route. For larger windows the cavity pressure will respond more quickly if openings are also provided at the head of the frame. This reduces the lag of the cavity pressure and will increase the effect of pressure-moderation. Providing openings at the head of the frame also aids ventilation of the cavity.

Summary

The key aspects of pressure-equalisation are:

1. An inner barrier highly impermeable to air;
2. A rainscreen so vented as to achieve a permeability far greater than that of the air barrier;
3. Compartmentation of the cavity to achieve an adequate ratio of cavity volume to opening area and so minimise air movement within the cavity and rapidly equalise the cavity and wind pressures.

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