Wind and Air Pressures on the Building Envelope

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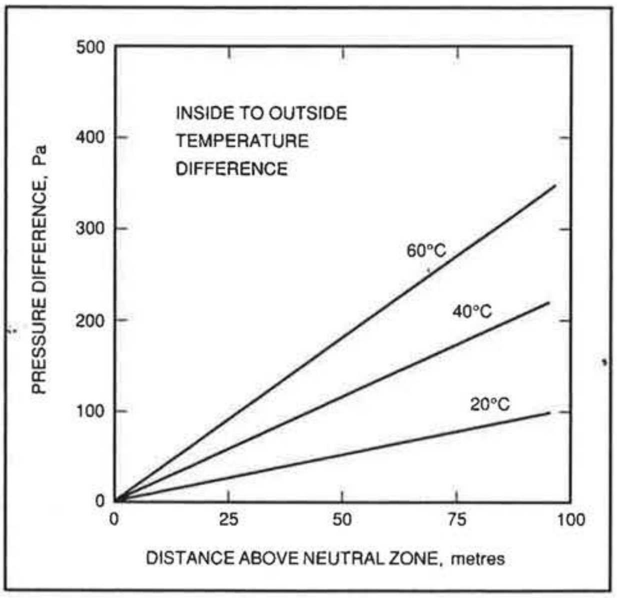
Mechanisms and Loads

Three different mechanisms can combine to influence the direction and magnitude of air pressures acting on a building envelope: stack effect, fan pressurization, and wind. The forces generated by each are usually known.

Stack effect and fan pressurization usually produce air pressure differences of between 5 and 10 Pa in houses and from 50 to 150 Pa in tall buildings. The pressure due to stack effect is height and temperature dependent, as shown in Figure 1.

Hourly wind pressure values for selected locations in Canada are listed in the Supplement to the National Building Code of Canada (NBC), in the climatic design data table. Values for individual locations range from 170 to 1500 Pa, but when adjusted for building shape and height, these may result in local pressures or suctions on the building two to three times greater. Wind gusts lasting 3 to 5 seconds can exert forces on a building in excess of 2500 Pa.

Figure 1 Theoretical draft in buildings due to stack effect



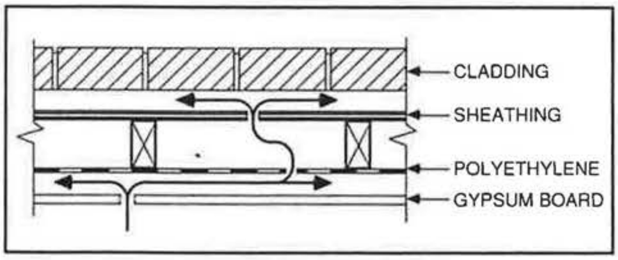
Resisting Wind and Air Pressures

Pressures acting on a building may be small but continuous, such as fan pressurization, or large but of short duration, such as wind gusts. How does a building envelope resist these forces?

If of frame construction, a building usually incorporates an exterior cladding, a sheathing, a vapour barrier and an interior finish, usually a gypsum board. In most buildings, none of these components have been installed so as to form an airtight assembly. As a result, the pressure difference that exists between the interior and the exterior of the building is often resisted by two or more components, but the air itself is able to flow in or out.

In the frame wall construction described previously, the three components (the sheathing, the polyethylene and the gypsum board) have some of the attributes required of an air barrier, such as continuity and air imperviousness. If there are small holes in each of these components and these holes are all interconnected by the spaces that separate them, internal pressure will cause air to flow through a hole in one component towards a hole in an adjacent one and so on until it reaches the outside of the wall, pressurizing the spaces as it moves through them (Figure 2). The gypsum board, the polyethylene and the

Figure 2 Air leakage paths through exterior wall



sheathing all support a share of the pressure difference (ΔP). For simplicity's sake, let's assume that each component supports one third of the pressure difference, as shown schematically in Figure 3(a). In practice this is unlikely to occur, because the number, size and location of the holes and the physical characteristics of the materials will influence the drop in pressure taking place across each component.

This condition can be changed dramatically by sealing all the holes in one of the components. If all holes in the plane of the gypsum board are plugged, as shown in 3(b), then air flow in and out of the building will stop and the gypsum board will have to support the entire air pressure difference across the envelope. Similar results would be achieved by plugging all holes in one of the other components. Thus to achieve an airtight enclosure, only one component needs to be airtight. To design a wall so as to make two or more components capable of resisting all air pressure loads is therefore wasteful.

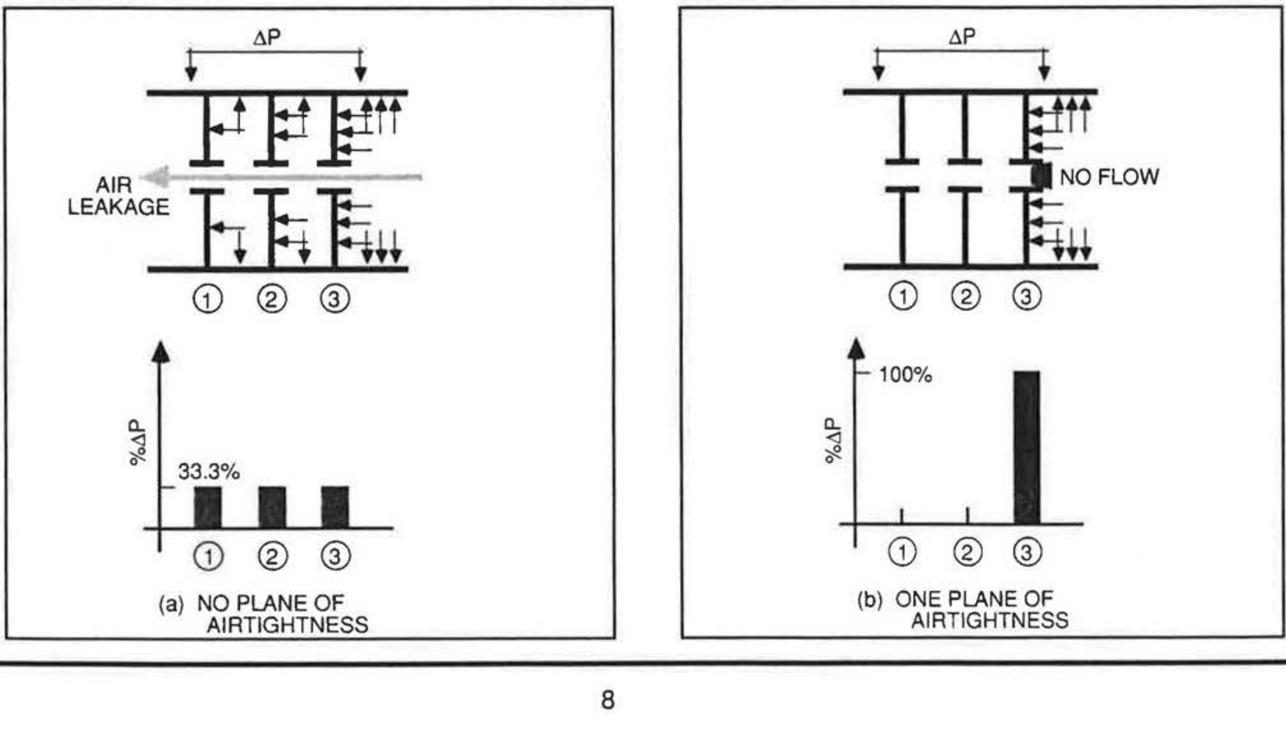
Compartmentation

In Figure 3 only static and uniform air pressures on the building enclosure are considered. Adding a steady wind pressure does not affect the internal pressures acting on the air barrier as long as the barrier remains intact. It does, however, modify the external pressures acting on it. A region of positive pressure (i.e. above atmospheric) develops on the windward side, while the other three faces experience negative pressures (i.e. below atmospheric), and the resulting suction is usually greatest adjacent to the corners.

Vented cavities are often installed behind claddings to prevent rainwater from entering the building. The variation in wind pressure along all four walls, however, causes air to flow inside the cavity as it moves from a region of positive pressure to one of negative pressure. This in turn influences how the wall performs under adverse weather conditions.

Figure 4(a) shows the plan view of one of the top floors in an office building. The outside walls are outlined by a double line: the dashed outer line represents the vented cladding; the solid inner line represents the wall's air barrier. Fan pressurization and stack effect account for the 100 Pa internal pressure, while the 160 km/h wind is responsible for the 1000 Pa positive pressure on the windward side. The –300 Pa pressure in the cavity is based on the interior pressure coefficients given in Figure B-11 of

Figure 3 Pressure difference (ΔP) across planes of airtightness



Commentary B "Wind Loads" of the Supplement to the NBC 1985 and assumes a continuous cavity all around the building, with openings uniformly distributed in all four walls, i.e., Cpi –0.3.

This drawing shows that where the wind is relatively free to circulate within a wall cavity, much of the wind pressure is resisted by the cladding and not by the air barrier; the cladding must be designed to carry the load.

The flow of air can also cause rainwater and snow to enter the cavity, where it can stain the façade or cause the deterioration of some of the materials in the wall. Such air flow can also have a detrimental effect on the performance of the insulation in the wall, adding to the heating and cooling costs of the building.

This flow of air can be prevented by dividing the cavity into compartments both horizontally and vertically, as shown in Figure 4(b). With the flow of air in the cavity stopped, the air pressure acting on the cladding is the same as that acting on the air barrier, thus eliminating the pressure difference across the cladding. This compartmentation can result in a more economical cladding design. Snow and rain cannot enter the cavity transported by the air, as happens in non-compartmentalized cavities.

Strength and Durability

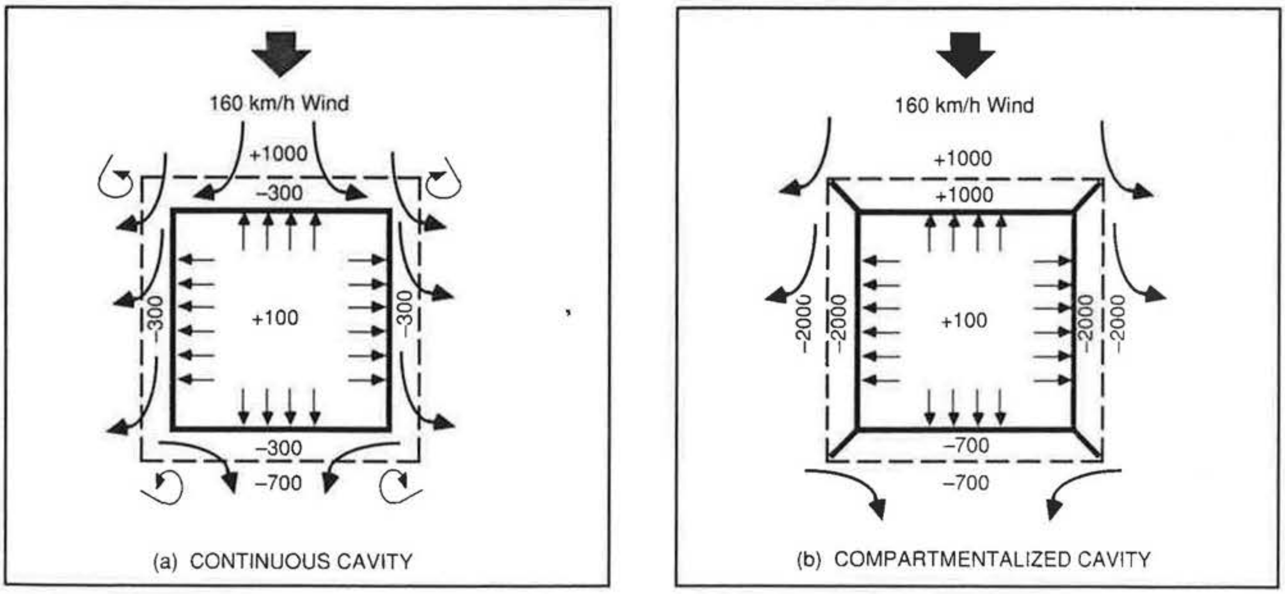
We have seen that the component selected to perform the role of the air barrier may have to resist continuous pressures in the 50 to 150 Pa range and peak loads of 2.5 kPa or greater during the life of the building. Unsupported polyethylene or other membranes used by themselves may tear at the supports and deflect under load, displacing insulation or other materials. They may also come in contact with a sharp object, resulting in a hole and loss of airtightness.

Other factors to consider when designing the air barrier are the rapidly changing gust pressures, which require the use of a rigid assembly; creep failure resulting from the continuous application of relatively small loads on sealants, tapes, self-adhering membranes, etc.; the large wind pressures that the materials have to resist; and the movements that all buildings undergo due to creep shortening or changes in moisture content of materials. All these can damage the air barrier and should be anticipated.

IRC Tests

In the early 1980s, the Institute for Research in Construction (IRC) undertook to measure air pressures across various types of wall construction in order to study how individual components in a wall respond to various loading conditions. The three types of walls included in the study were (1) a wood frame wall used in residential construction, (2) a precast concrete wall designed as a pressure-equalized rain screen installed in a medium-rise building, and (3) a brick veneer and steel stud back-up wall used in a low rise building.

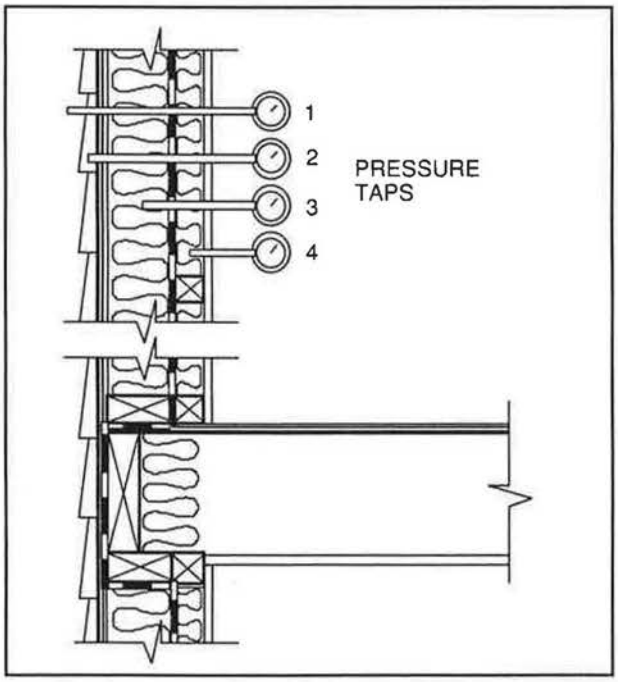
Figure 4 Cavity air flow, pressures and compartmentation



The Wood Frame Wall

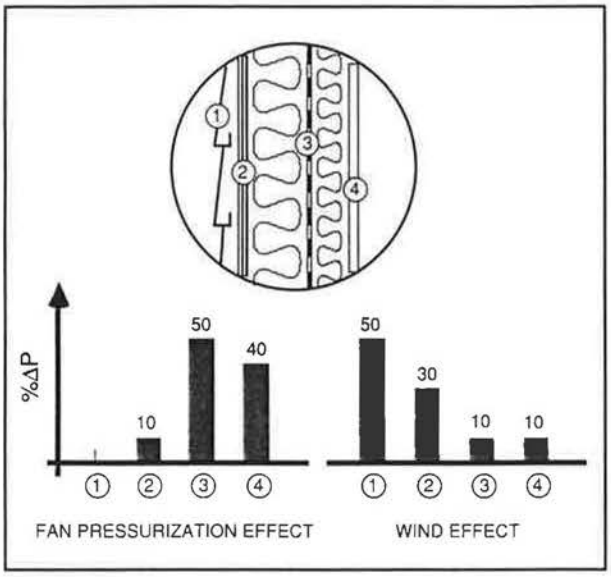
The design of the wall is shown in Figure 5. The distinguishing feature is the placement of the polyethylene vapour barrier part way into the insulated portion of the wall, allowing all electrical wiring to be installed without puncturing the vapour barrier. The objective was to make the vapour barrier as airtight as possible. Pressure taps were installed as shown to measure the air pressure 1) on the cladding, 2) in the space between the cladding and the sheathing, 3) between the sheathing and the vapour barrier, and 4) between the vapour barrier and the drywall. Since the designers intended the vapour barrier to double as the air barrier, its installation was well detailed and was discussed with the builder. The results, however, were disappointing (Figure 6). During the fan pressurization test, performed on a calm day, the vapour barrier resisted 50% of the load, while the gypsum board supported 40%, and the sheathing 10%. Under windy conditions, however, the vapour barrier and the gypsum board each supported only 10% of the wind load, while the cladding supported 50% and the sheathing 30%.

Figure 5 Pressure taps in wood frame wall



These results indicate that because the wind is relatively free to flow between the cladding and the sheathing, the cladding must carry most of the wind load. The polyethylene, sandwiched as it is between two layers of low density insulation, deflects easily under load and as a result supports little of the wind load.

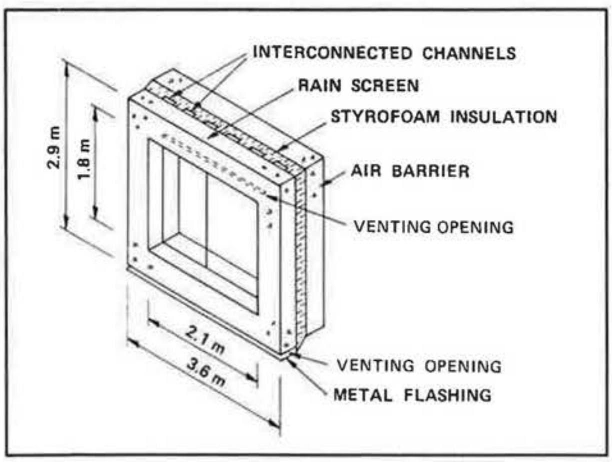
Figure 6 Air pressures on wood frame wall



Precast Concrete Wall Panels

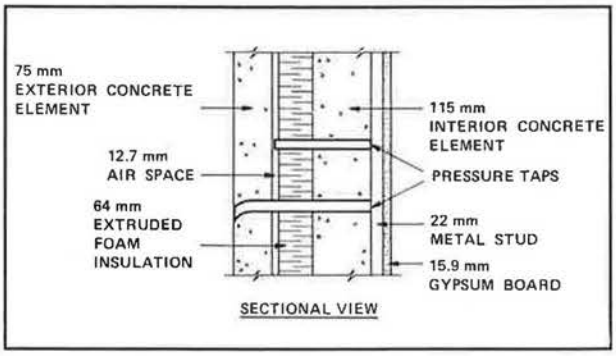
These precast concrete wall panels were designed to perform as a pressure-equalized rain screen. They consist of two thicknesses of concrete separated by a 77 mm cavity containing 64 mm of foam insulation. The exterior concrete layer is the rain screen, while the inside one acts as the air barrier. Rectangular and measuring 3.6 × 2.9 m, each panel contains an opening for a window (Figure 7). The air space separating the two concrete layers is sealed at all edges except for a continuous 15 mm slot in the bottom of the panels and one above the window, which allow for wind pressurization of the cavity. Twelve panels installed on the 24th floor of a 27 storey office building contained pressure sensors which were attached to pressure transducers and a data logger. The 24th floor was selected because

Figure 7 Rain screen panels



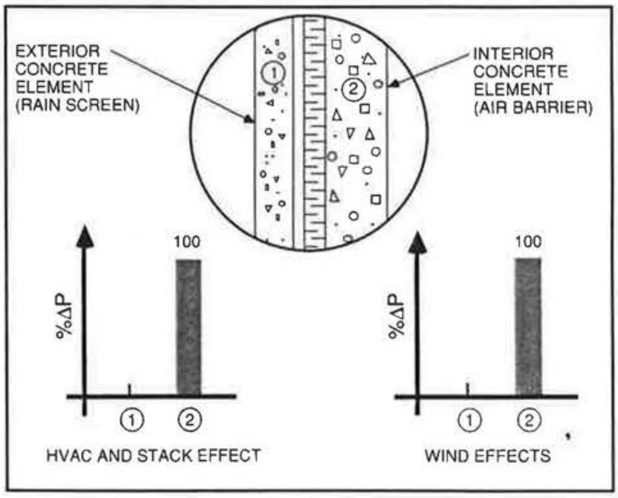
maximum wind pressure on a building generally occurs at about 85% of the building height. The pressure taps are shown in Figure 8.

Figure 8 Pressure taps in precast concrete wall



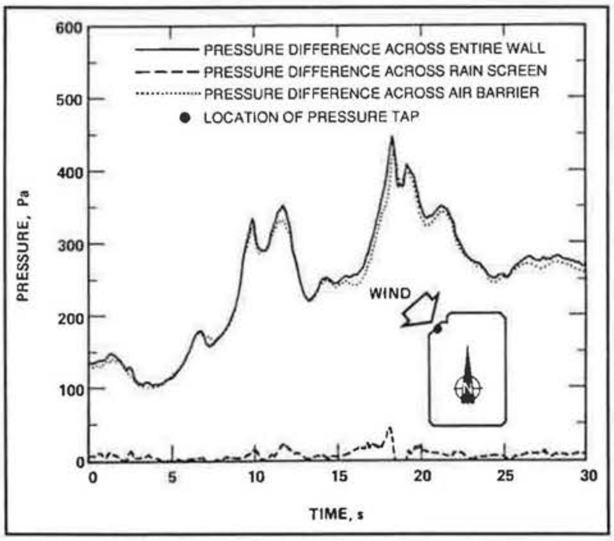
On a calm day the building interior of the 24th floor was pressurized using the HVAC, and the entire pressure difference including stack effect was measured across the air barrier (the interior concrete layer and the sealant in the joints between panels) showing that the two constituted the plane of airtightness (Figure 9). On windy days it was observed that the entire wind load was supported by the air barrier most of the time. Pressure differences amounting to 15% or less of the wind load and lasting only a few seconds were measured across the rain screen ($P_e - P_c$ on Figure 10).

Figure 9 Air pressures on concrete panel wall elements



There were occasions, however, when the pressure difference measured across the rain screen was greater than that shown in Figure 10, i.e., from 50 to 75% of the maximum wind load. These larger forces, which lasted less than one second, remain unexplained but could have been caused by small eddy currents (not much larger than the pressure taps themselves) impinging on the face of the panels, so that the entire panel may not have been subjected to the higher loadings. In any event, since the largest pressure difference measured across the rain screen was at least 25% lower than the maximum wind pressure on the building, it would be possible to save money by designing the rain screen to meet this reduced loading.

Figure 10 Wind pressures on concrete panel wall elements



Brick Veneer and Steel Stud Walls

The walls of the building used in this study incorporate a drained and vented cavity to remove moisture penetrating through the brick. Ten panels were instrumented, with two taps mounted through the brick and one set in the cavity. The two taps were set in the brick veneer to investigate the existence of small eddy currents giving much higher readings when striking a single tap but not necessarily reflecting the actual loading on the panel. Using two taps spaced a short distance apart would result in very different readings if these small currents existed.

The interior space of the three storey building was pressurized on a calm day using the ventilation system. Measurements recorded a 70% pressure drop across the steel stud back-up wall and the remainder across the brick veneer (Figure 11). This appears to indicate that the inside stud wall is more airtight than the brick veneer. Under windy conditions, however, the reverse is true: 70% of the pressure drop due to the wind takes place across the brick veneer, probably because it is of stiffer construction than the back-up wall and because of the lateral flow of air in the cavity.

Figure 11 Air pressures on brick veneer and steel stud wall

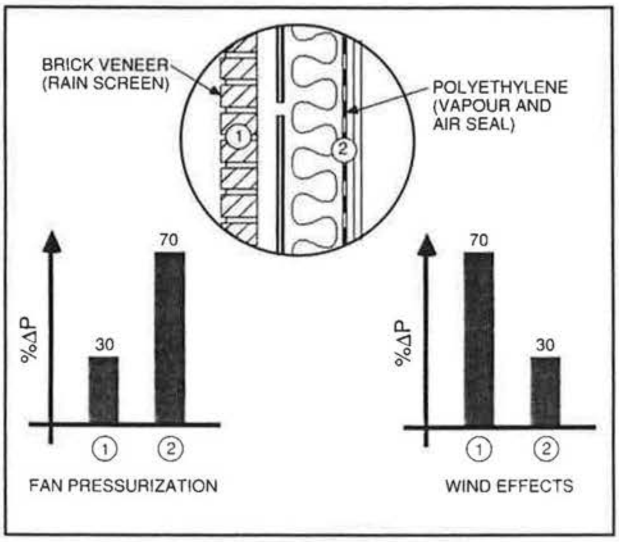
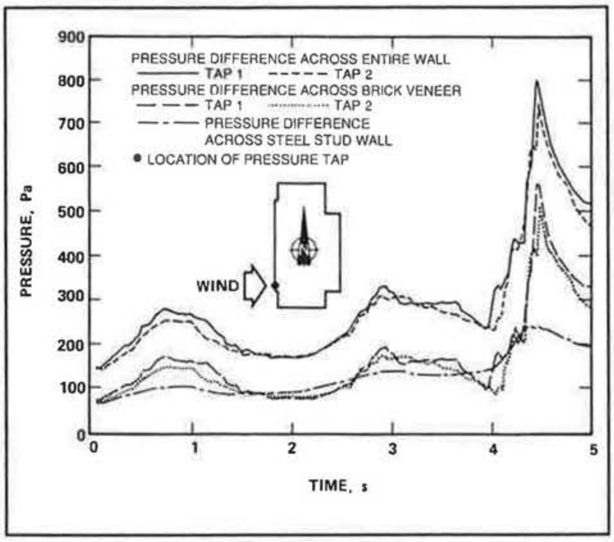


Figure 12 shows a five second record of wind pressures on the brick veneer and in the cavity between the brick and the metal stud wall. The following observations can be made based on the information presented:

a) the wall system had to support high peak pressures (800 Pa); within one second the pressure increases from 225 Pa to 800 Pa and decreases to 500 Pa;
b) under gusting conditions the brick veneer supports approximately 70% of the wind pressure;
c) the theory that small eddies impinge on the surface of the panels causing large differential pressures was not supported by the data collected, as both taps registered similar pressures throughout the testing period.

Figure 12 Wind pressures on brick veneer and steel stud backup wall



Summary

In conclusion, of the three buildings which were instrumented in the field, only one had an exterior envelope which could be described as a pressure equalized system, that is, the precast one. The cavity of an open rain screen wall system will be pressure equalized when the cavity is adequately compartmentalized and when the leakage of the air barrier system is considerably smaller than the venting area of the rain screen cladding.