Air Leakages. Condensation.
Failures. Joints (Junctions).
Rain Penetration. Smoke Control.
Stack Effect. Two-Stage Joints.

Rain and Air Leakage at Joints.

G. K. Garden.

Known principles for the prevention of rain penetration and air leakage are not being applied in practice. Rain penetration requires the simultaneous presence of water, of openings and of a force; the two-stage weathertightening, or "open rain screen" joint separates the control of these factors, and allows the production of a weathertight joint under practical conditions. Air leakage can occur as a result of pressure differences – between interior and exterior – caused by the chimney effect, wind and mechanical pressurization. The pressure differences are almost inevitable, and the control of air leakage requires a "structural" air barrier, best located at the constant-temperature side of the thermal insulation. Air leakage is a significant contributor to the movement of smoke in case of fire. Case-histories show the gravity of the problems that can arise, due to air leakage.

Introduction.

Despite the fact that field-proven scientifically-correct principles for joint design have been available for many years, there are still too many failures. *Rain leakage* problems persist because these principles are not being followed and *air leakage* problems are occurring because its mechanisms are not being given due consideration.

The two stage weathertightening, or "open rain screen" concept is becoming well established and rain leakage to the interior, through building walls and windows, could easily become a problem of the past. The term "open rain screen" however, is unfortunate because designers are misled into thinking that they are only dealing with rain penetration. The term "two stage weathertightening", used in Europe, is more appropriate, for it suggests that the entry of water is controlled at an outer layer or first stage but that air leakage must be controlled at a second stage or inner layer. It also indicates that the air leakage control is necessary to gain the rain penetration control (see fig. 1).

The two-layer concept of the two stage weathertightening of the joint – in dealing with rain penetration and air leakage – also controls heat, air and moisture, namely the prime functions of exterior walls, in a way that takes account of the factors influencing the environment of the various materials of the construction, and consequently of their durability or service life. 2246

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Case Histories.

It is not necessary to discuss examples of *rain penetration,* for they all occur simply because the two-stage weathertightening approach to joint and wall design is not being employed. There are, however, many buildings experiencing problems due to *air leakage* because the importance of the mechanism is not recognized or appreciated. Discussion of a variety of problem situations should be of considerable value in altering this situation.

1. Air leakage due to wind pressures.

There are many buildings, of all sizes, experiencing thermal problems due to air leakage, whether they are recognized or not. Many houses, for example, are chilly in some rooms when the wind blows in winter, and – in general – a large percentage of the heating load in most buildings is due to the amount of air leakage through the walls [1].

A very severe thermal problem occurred recently in a large building constructed in the low arctic. The metal skin on the inner side of the thermal insulation was not air sealed and furthermore, most of the sealed joints of the outer cladding failed due to movement at the extreme low temperatures encountered. Despite the doubling of radiation in each of the rooms at the northwest end of the building, the temperature would drop considerably below freezing when there was a strong wind from that direction. At the same time, because of the increased heat input, the rooms at the leeward end of the building were extremely overheated.

2. Air leakage due to chimney effect.

Because of air leakage through the walls of an 18 storey building, the lower three floors were underheated. There was only a modest humidification of the air, yet there was condensation in the upper walls and the formation of large icicles which presented a considerable hazard to people on the streets below. Recognizing the cause of their problem, after three years of operation, the owners spent a considerable sum of money in reducing the air leakage of the walls. Over the following winter it was discovered that the *savings* from the previous annual fuel bill amounted to over 35% of the cost of the corrective work; the condensation problems had been almost eliminated.

Severe condensation problems in the ground floor swimming-pool room of a seven storey apartment house occurred because of infiltration of cold air. Ice and frost to 3" thickness formed on the walls and window frames and the general coolness of the room made it unusable in cold weather.

Air exfiltration and the condensation accompanying it through the upper walls of a thirty storey metal and glass clad curtain wall building caused such large icicles that a busy street had to be cordoned off when the icicles started to fall.

(1) *0.018 btu are required to heat each cubic foot of air one degree fahrenheit.*

The masonry parapet walls of a humidified art gallery building were so badly deteriorated that complete reconstruction was necessary after only one winter of operation. To solve the problem, however, it was necessary to work on the *interior* surfaces of the exterior walls to stop exfiltration of the humidified air.

While inspecting a building during January one year, the caretaker complained that the sealing of the wall joints had failed again, "for there was rain leakage right then", yet there had been no rain for many months! It was a mild day following a long cold spell; the walls were precast concrete panels with foamed plastic insulation and a drywall finish on the interior. Examination showed that the network of small voids between the insulation and concrete panels had filled with condensation in the form of frost which was now melting and causing the problem which looked – at first glance – like rain penetration. The frost formed in the wall as a result of warm building air moving by convection through the joints in the insulation above the suspended ceiling, down through the cold spaces between the insulation and the concrete panels and returning to the room under the base board.

Fire Hazards and Air Leakage.

In recent years, there has been increasing concern for life safety during fires in buildings, particularly since it is impossible to evacuate tall buildings in a reasonable period of time. It has been established that when there is a fire below the half-height of the building, smoke rises through stair and elevator shafts to fill the upper floors with smoke. The rate and severity of this smoke movement is directly related to the air leakage characteristics of the walls. For example, a chesterfield caught fire in the lobby of an apartment house and within minutes the upper floor was completely smoke filled. In a tall hotel, a fire on the ground floor resulted in smoke filling the top five floors to the extent that oxygen equipment was required for the evacuation of the few guests that were in the hotel at the time.

As was mentioned before, the pressure differences causing the chimney effect *always* exist, but the associated smoke and air flow *only* occurs if air leakage also occurs.

Conclusion.

Rain and air leakage at joints can and must be prevented. It can be stated that the pressures which cause air leakage will almost inevitably occur, but actual leakage will not occur if there are no air leakage paths. This normally requires a "structural" air barrier located at the constant temperature side of the thermal insulation, in other words, where it will be protected from the temperature changes of the outside. With industrialized building systems, where simplicity of assembly is all-important, it is essential to design the elements and components in such a manner that the air sealing of the joints is simplified and yet effective. It is also clear that great economy for the user, as well as better building performance, can be realized if more attention is paid to gaining positive air tightness.

Acknowledgement:
Fig. 2 is reproduced from Canadian Building Digest 40 with permission.

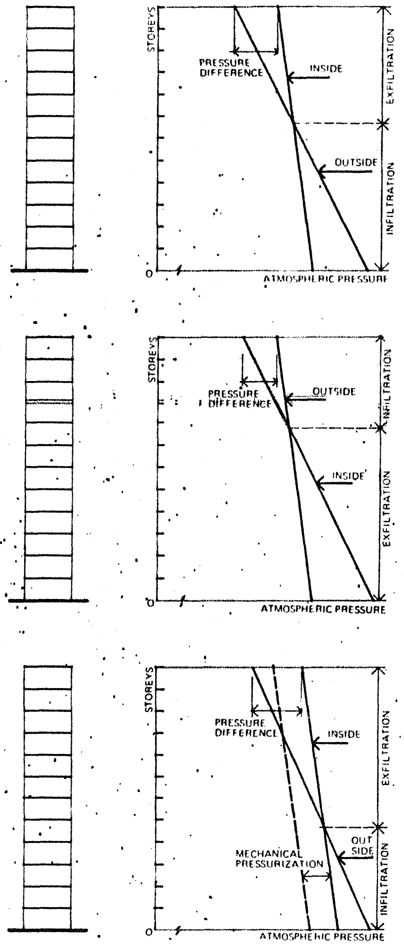

Figure 3. Air Pressure Differentials between Interior and Exterior of a Tall Building; (a) in Winter, Heating on; (b) in Summer, Cooling on; (c) in Winter, Heating and Mechanical Pressurization on.

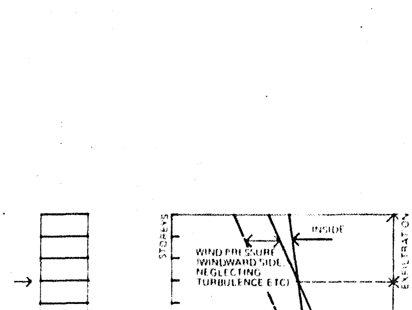

Figure 4. Air Pressure Differentials between Interior and Exterior of a Tall Building, in Winter, Heating on and Wind Blowing.

1. Air infiltration; leakage of air from outside to inside a building.
2. Air exfiltration; leakage of air from inside to outside a building.
3. Convective interchange of air from inside the building with air in spaces in the walls.
4. Convective interchange of outside air with air in wall spaces (commonly referred to as "venting").

Only the fourth mechanism can be considered beneficial, and even then only when the air does *not* pass inside the thermal insulation.

The air pressure differences causing *infiltration* and *exfiltration* are due to (i) the chimney effect of the building, (ii) wind and (iii) mechanical pressurization of the interior spaces. The two *convective mechanisms* occur because of a chimney effect due to the difference of temperature in the wall spaces and the building interior or exterior as the case may be; venting can also be influenced by wind pressure variations.

The chimney effect (fig. 3a) in heated buildings during cold weather produces pressures causing air infiltration at lower floors and air exfiltration at upper floors. In cooled buildings in warm weather the pressure patterns are reversed (fig. 3b). Mechanical pressurization accompanying winter heating seldom achieves more than a slight reduction of infiltration but increases the exfiltration pressure at upper floors (fig. 3c). Wind on a building causes an infiltration pressure over most of the windward surface of a building but causes exfiltration pressures at the top and edges of the windward wall and across all other walls (fig. 4). The pressure differences causing convective interchange of air occur any time the temperature in the wall space is different from the temperature of the adjacent air mass.

Infiltration causes an increase of heating and cooling loads, entry of dust, odors and other pollutants, cold drafts, difficulty in maintaining thermal comfort and humidity control, and is instrumental in producing interior surface condensation adjacent to air leakage paths. *Exfiltration* from a humidified building causes condensation within the wall construction, with the risk of severe damage to materials and construction, particularly during cold winter conditions. The convective transfer of air between cold spaces in the wall and the building interior also causes interstitial condensation and the associated problems. It should also be stressed that the chimney effect in a heated building, due to differences in pressure, produces the tendency for air to rise through the building, with the actual *flow* of air being greatly influenced by the air leakage characteristic of the exterior walls, windows and roof.

Air tends to move through a construction because of an air pressure difference; thus to control air leakage requires that there be a totally continuous air seal; the element preventing air leakage must itself have sufficient strength, or be sufficiently supported, to withstand the total load applied to it. This load, due to wind, chimney effect and mechanical pressurization can exceed 35 psf inward and 50 psf outward on a 200 foot high building. Because a material, subjected to temperature variations, tends to move, and joints can be opened or the material cracked, the pressure-containing air-barrier element of the enclosure must be located at the constant temperature side of the thermal insulation for best performance.

The entry of water by the kinetic energy of the rain drop is prevented where there are no direct openings which would let the rain drop fly into the construction. Gravity, acting to cause water to flow downward can cause leakage through passages that lead inward in a downward direction; a space in the joint or wall, with no bridges across it and drained outwards by a flashing at the base, can control the flow to prevent leakage due to this force. Capillary suction acts to draw and hold water in small passages; if these passages are not continuous to the interior, e.g. by inclusion of a space in the leakage path that is larger than capillary dimension, leakage to the interior due to this force can be prevented. An inward air pressure drop between outside and inside, across the wetted surface, occurs under wind driven rain conditions; if however, a space in the joint or wall is provided immediately behind the wetted surface, and if it is always at equal pressure to the outside, this force will not occur across the wetted exterior surface and water will not be moved inward. This equalization of pressures, however, requires that there be an effective air seal between the pressure equalization space in question and the building interior, to restrain the air pressure difference that almost inevitably occurs between outside and inside as described in the next section. It is the control of this pressure difference, the main force causing rain leakage, that characterizes the two layer joint, to which the two names: "two stage weathertightening" or "open rain screen" joint. This joint is illustrated, in its most used form, in figure 1.

Considering the preceding discussion, it is now clear that the forces causing water to move inward *can* be controlled and water leakage prevented *despite* the occurance of openings which would seem to permit the passage of water and air. It must be emphasized here that the principles involved are not merely scientific theory but a practical demonstration of how Nature can be controlled by compliance with Nature's own laws. In building science, it must always be borne in mind that "to *control* Nature, requires that you *obey* Nature".

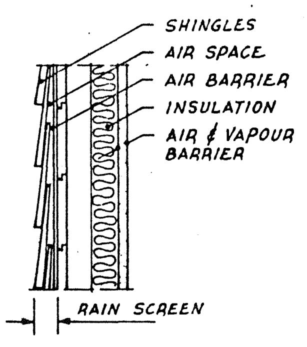

Figure 2. Cross-Section of Shingled Wall; this Wall — Despite Many Openings between the Shingles — is Weatherproof.

It is worth noting that it is the same principles that explain why a shingled wall, despite a miriad of open joints, is so successful in preventing rain penetration (fig. 2). Incidentally, it is also because of these same principles that it is possible to sing in the shower without drowning.

Air Leakage.

The importance of air leakage as a contributor to building problems is not being sufficiently recognized and is not receiving due consideration in design and construction. With the ability to provide humidification of the interior environment and with the trend toward taller buildings, the problems associated with air leakage are becoming more severe.

Air leakage should be considered under four types, all of which occur because there is an air pressure difference across an element of a building — typically the outside wall — through which there are openings to permit the air leakage in question:

Rain Penetration.

Rain leakage of walls, or for that matter, leakage of water through anything, occurs only when there is water on the surface, an opening to permit the water to pass through and a force to move the water, *all occurring simultaneously.* It is obvious, then, that if any one of these three conditions is eliminated, leakage cannot occur.

It is possible, in some situations, to prevent water from being in contact with a surface, in which case there would be no potential leakage. With walls, windows and roofs, however, it must be accepted that water will, at some time or other, be in contact with the surface.

There are normally a multitude of openings through walls such as the pore system of the materials, fine cracks, poorly bonded interfaces, or minor failures of sealing devices. Where a totally impermeable *surface* exists, such as where waterproofing membranes have been successfully applied, leakage is prevented. Impermeable *materials,* glass and sheets of metal or plastic, prevent leakage except at the inevitable joints between pieces of the material or at the joints with other materials. It must be accepted that there will normally be openings which will permit the passage of air and water at these joints.

With water on a surface *and* openings through which it can pass, the water will still not move through the opening unless there is a force or combination of forces acting to move it through. The forces causing leakage are: the kinetic energy of the rain drop, gravity, capillary suction, and an inward drop of air pressure. If all four forces are properly controlled or prevented from occurring *at the wetted plane,* leakage will not occur.

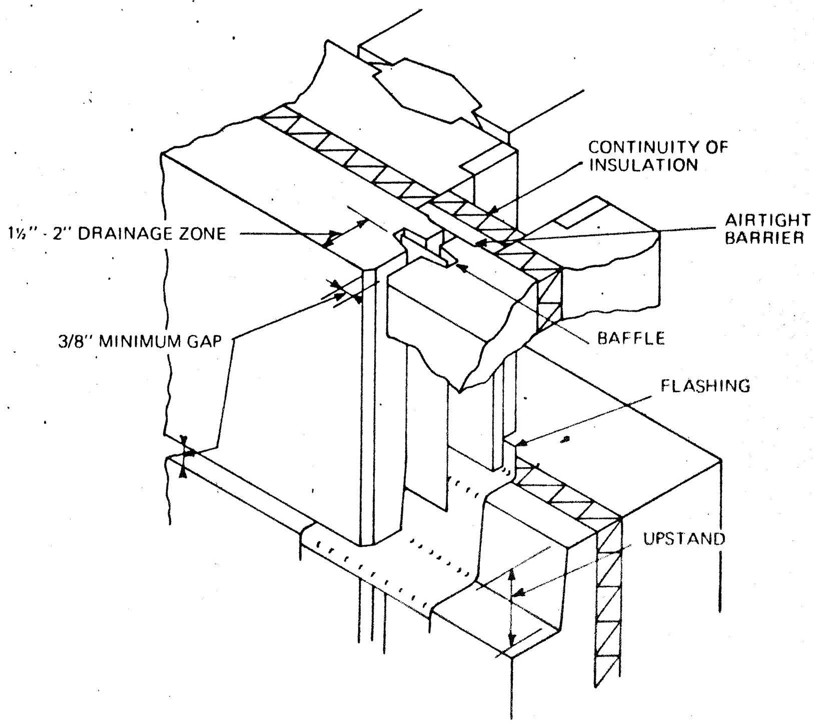

Figure 1. Two-Stage Weathertightening Joint; Typical Detail of Cross-Over of Horizontal and Vertical Joints.