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MOISTURE ACCUMULATION IN WALLS DUE TO AIR LEAKAGE

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In temperate and cold climates, this effect is greatest during the winter. Under the influence of chimney action alone, air flows into the building through openings at lower levels, flows upwards in the building and out at higher levels. Somewhere between, there is a level at which no in- or out-flow occurs, sometimes referred to as the neutral zone, where the pressure inside equals that outside. The theoretical pressure difference across the enclosure at any level is equivalent to the difference in weight per unit area of inside and outside columns of air between the level and the neutral zone. Table I indicates the magnitude of these pressure differences.

Table 1. Pressure difference due to chimney action (distance to neutral zone = 100 ft (30.5 m)).

Temperature Difference		Pressure Difference	
°F	°C	in. H_2O	kg/m^2
20	11.1	0.055	1.39
40	22.2	0.115	2.92
60	33.3	0.179	4.55
80	44.4	0.250	6.35
100	55.5	0.326	8.28

The neutral zone level for a building depends upon the vertical distribution of cracks and openings in the enclosure; published data are few. Measurements across entrances of tall office buildings by Min [1] indicate an apparent level of the neutral zone of 70 per cent of the building height for conventional construction and 30 per cent of the height for a very tight modern building. In recent measurements by the Division of Building Research on a new 9-storey office building, with masonry curtain walls and alternate sealed and openable windows, a level of 56 per cent of the building height was established with all mechanical supply and exhaust systems shut down and sealed. The pressure difference at any level was reduced to approximately 80 per cent of theoretical values due to resistance to vertical flow within the building. Vertical air flow occurs via elevator and various service shafts and stairwells. Recorded experience indicates that sealing against vertical flow is usually quite imperfect in buildings as normally constructed. If perfect sealing at each floor were possible, the effective chimney height would be limited to the distance between floors.

It should also be recognized that chimney action can occur between the air in the building and colder vertical air spaces in the building envelope when openings exist at two or more levels. For example, significant air interchange can take place between the space of a double window and the inside of the building [2];

similar flow occurs in furred pipe spaces in the outer walls which are often open to heating or air conditioning units at floor level and to spaces above suspended ceilings. Air flow can then occur from the room into the wall space at upper levels and out to the room at lower levels.

It is not uncommon in Canada for engineers to design and operate mechanical ventilation systems to provide an excess of air supply over exhaust in order to pressurize the building. Generally, the purpose of pressurization is to reduce infiltration at doors and windows to improve comfort and inhibit the entry of air pollutants; sometimes it may be inadvertent. The effect on pressure differences across the enclosure will depend upon the air tightness of the building and the amount by which supply air exceeds exhaust. Little, if any, published information obtained by test is available on the air tightness of large buildings. In measurements by DBR on the 9-storey building referred to previously, pressurization of the building as normally operated varied from 0.01 to 0.09 in. (0.25 to 2.3 mm) of water. With the exhaust system shut down, and the supply system providing outside air equivalent to about 3.2 air changes per hour, the building pressure was about 0.18 in. (4.6 mm) of water higher than outside. Measurements on a very high metal curtain wall building with sealed windows indicate that pressurization up to 0.5 in. (12.7 mm) of water may occur with normal system operation, and that higher values can be induced. Very substantial pressure differences due to mechanical ventilation systems are thus possible. When superimposed on normal chimney action, with excess supply air introduced uniformly at all floors, the effect is to reduce the pressure difference at the bottom of the building approximately by the amount of pressurization and to increase the pressure difference at the top by a similar amount. The neutral zone level is lowered correspondingly. Infiltration is thus reduced at lower levels and exfiltration increased at upper ones.

Infiltration of air due to wind on the windward sides of buildings is widely recognized. At the same time, wind action produces negative pressures and a potential for exfiltration on leeward sides. Negative pressures can also occur at the top of walls in the vicinity of parapets and along the corners, even on windward sides. Wind pressures around buildings are usually expressed in terms of the wind velocity head. Positive pressures generally vary from 0.4 to 0.9 of the velocity head; negative pressures are usually a smaller fraction, but can have values greater than unity. The pressure inside a building under wind action depends upon the external pressure pattern and the distribution of openings in the enclosure. Measured values of pressure difference across the leeward walls of the aforementioned 9-storey building at the vertical centreline, expressed as a fraction of the velocity head of the wind above the building, were as high as 0.35 at the top and 0.25 at the bottom. It will thus be seen from Table II that wind action can produce a significant potential for air exfiltration.

Table 2. Pressure due to wind.

Wind Speed		Velocity Head	
mph	m/s	in. water	kg/m^2
5	2.24	0.012	0.304
10	4.47	0.048	1.220
15	6.71	0.104	2.590
20	8.94	0.193	4.910
25	11.20	0.301	7.620

AMOUNT OF CONDENSATION DUE TO AIR LEAKAGE

The extent of condensation due to air leakage depends on the quantity of air flow, its initial moisture content, and the reduction in temperature that it undergoes in passing through the building envelope. The volume of air exfiltration depends on the air pressure differences, the time over which they prevail, and the leakage characteristics of the construction. These will vary with the building and climate. In general, moisture problems due to exfiltration will increase with increasing building height, decreasing average winter temperature, and increasing building humidity.

Published information on leakage characteristics of construction, other than windows, is not extensive. To illustrate the potential for condensation in walls due to air leakage, consider a 12-in. (30 cm) thick unplastered brick wall with no inside finish. Masonry is commonly left unplastered between suspended ceilings and the floor above, and behind recessed heaters or air conditioning units under windows. The air leakage through each 100 sq ft (9.3 sq m) of wall can be taken as equivalent to that through a sharp-edged orifice having an area of 3.1 sq in. (20 sq cm) [3]. To represent the cumulative effect of a winter season on moisture transfer through upper walls in humidified multi-storey buildings, it is not unrealistic to assume, for colder Canadian climates, that the following average conditions prevail for 100 days: inside temperature and relative humidity of 73°F (23°C) and 30 per cent relative humidity; outside temperature of 15°F (-9°C); pressure difference inducing exfiltration of 0.15 in. of water (3.8 kg/m^2), equivalent to a distance of about 80 ft (24 m) from the neutral zone.

The heat and moisture exchange between the flowing air and masonry will be complex. If it is assumed that the air leaves the cold side of the wall saturated at outside temperature the total moisture deposited in the masonry in 100 days is 735 lb per 100 sq ft (36 kg/m^2). It is of interest for comparison to approximate the amount of moisture that might be deposited by vapour diffusion; again the real situation is most complex but simplification is appropriate for present purposes.

Taking as the potential for moisture deposition the difference between the room vapour pressure and saturation vapour pressure at outside temperature, and taking an average permeance value for the brick of 1 perm (2.02×10^{-6} kg/m^2h pr. kg/m^2), the moisture deposited is 4.5 lb per 100 sq ft (0.22 kg/m^2). Air leakage thus present a significant potential for moisture deposition that can be two or more orders higher than that due to diffusion. Furthermore, moisture deposition due to air leakage may be concentrated in the vicinity of the cracks through which air flow occurs.

FIELD OBSERVATIONS

Many cracks and openings, through which air can exfiltrate, exist or develop in modern buildings, and resulting moisture damages take many forms. A few examples are given in the following section.

Disruption of masonry (Figure 1) occurred during the first winter after occupancy, at the top of the walls of a masonry-clad, steel-frame, humidified building. With the aid of smoke, it was determined that air was leaking outwards through the unplastered portions of the masonry walls (e.g. above suspended ceilings) and through cracks between structural elements and the masonry. Moisture accumulations (due to condensation) were found to be concentrated adjacent to air leakage paths. Further examination showed that the same problem occurred below window sills (Figure 2). Figure 3 indicates the construction, and patterns of air leakage and condensation at the window sills. The moisture and thermal conditions in both these cases were conducive to the growth of ice lenses [4] in the mortar joints, which caused the disruption of the masonry and lifting of window sills. Other

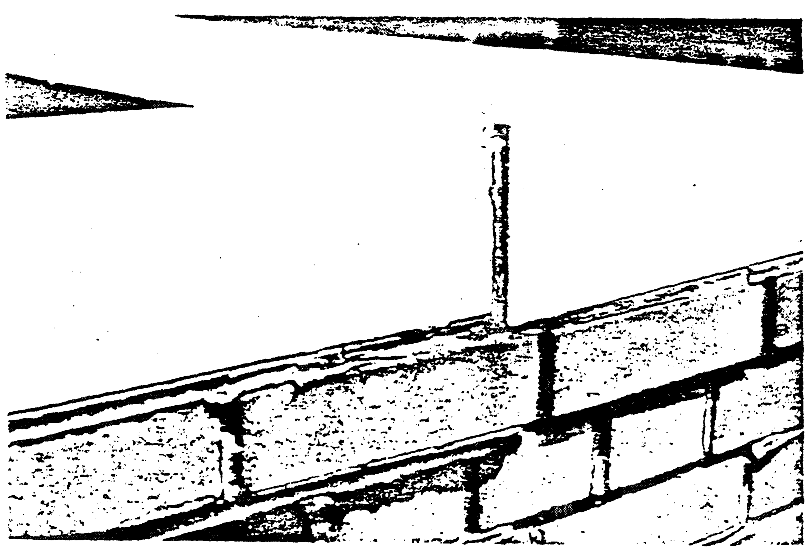

Figure 1. Disruption of masonry by frost action in wet materials.

Figure 2. Damage to masonry at window sills as a result of excess moisture from condensation associated with air leakage.

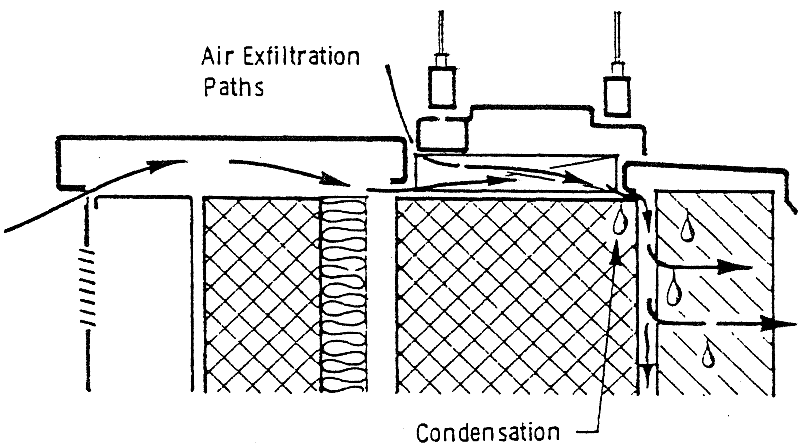

Figure 3. Diagram of window sill showing air leakage paths and location of condensation.

areas on the building subjected to suction from the prevailing wind also showed indications of moisture accumulation.

In this building, air exfiltration through the spaces between double windows produced excessive condensation on the inner surface of the outside pane of glass. The pattern of air pressure differentials was easily seen as the windows at the seventh (or top) floor of the building had a great accumulation of frost while those at the bottom remained relatively clear.

During cold weather, there was continual dripping of water from wall drain holes at window heads of a high-rise metal and glass curtain wall building. The formation of icicles the size of a man's arm at window heads some 400 ft above the street caused considerable alarm. The design of this curtain wall followed the common practice of endeavouring to seal the outside surface of the wall against rain penetration; it was assumed that this would also provide adequate air tightness. Recognizing, however, that any wall designed on this basis did eventually leak in rain storms, the spaces within the wall were designed to lead the water to the exterior through drain holes in the window heads. No attempt was made to provide a seal against air flow at interior surfaces so that cracks and openings leading to window mullion and wall spaces occurred regularly throughout the height of the building. Air interchange between the building interior and these cold spaces produced condensation with constant dripping of water from window heads and soiling of the windows throughout the winter. At floors above the neutral zone, air exfiltration through the exterior drain holes increased the rate of moisture accumulation and the severity of the problem at higher levels. Because the building was highly pressurized, air exfiltration occurred over most of its height. Condensation, stored as frost, melted when the outdoor temperature rose to about 25°F (-4°C) after a prolonged cold spell. From the 36 ft (11 m) of wall enclosing mechanical rooms at the top of the building, water flowed out the drain holes at the top row of windows and formed large icicles.

Staining and stone displacement occurred in a building (Figure 4) due to moisture accumulation in the column cladding. The building was not intentionally humidified but the walls were relatively airtight and the mechanical system was inoperative, so that moisture added to the air by breathing, floor washing, and melting of snow from footwear caused a moderate increase in humidity. The humidity level was not constant nor was it sufficient to produce objectionable condensation on the double glazing or metal window frames.

The window jamb detail in Figure 5 shows that the insulated mechanical lines were concealed in wall spaces outside the building insulation. Above the suspended ceiling, the wall finish was omitted and near the floor, the run-outs serving the bank of heating convectors passed through the wall finish. Air interchange between the building and the pipe spaces due to chimney action resulted in condensation on cold surfaces whenever the humidity was high enough. Since it accumulated as frost, sustained conditions for condensation were not necessary to provide a large quantity of water. Upon thawing, most of it was absorbed by the backup mortar. Refreezing of the water in the mortar produced ice lenses that displaced the column cladding stones (Figure 6). Once the cladding was displaced, air exfiltration increased and contributed to the moisture accumulation, as did rain penetration at certain times of the year.

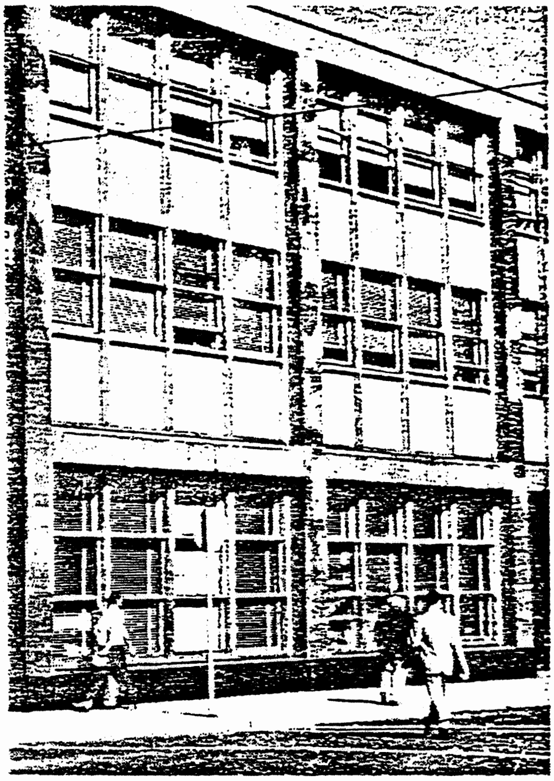

Figure 4. Condensation from air interchange between the building and spaces within the wall produced stains, discolorations and stone displacement.

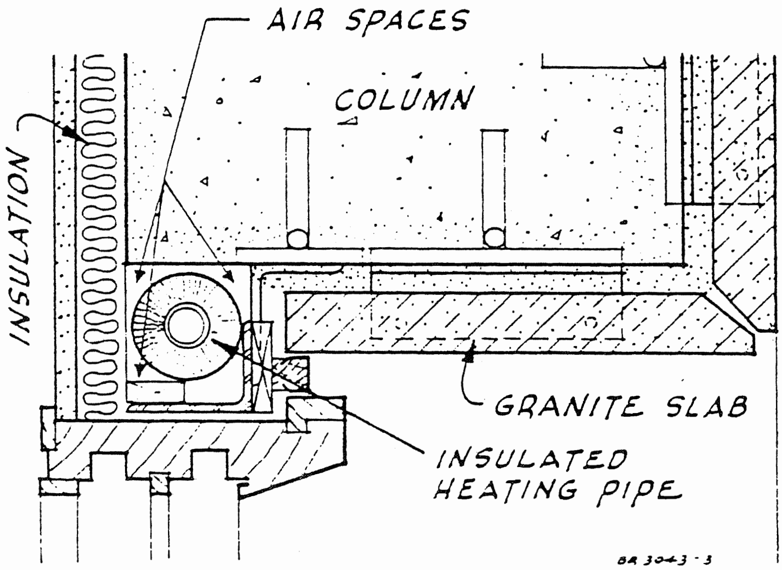

Figure 5. Window jamb detail showing spaces within the wall.

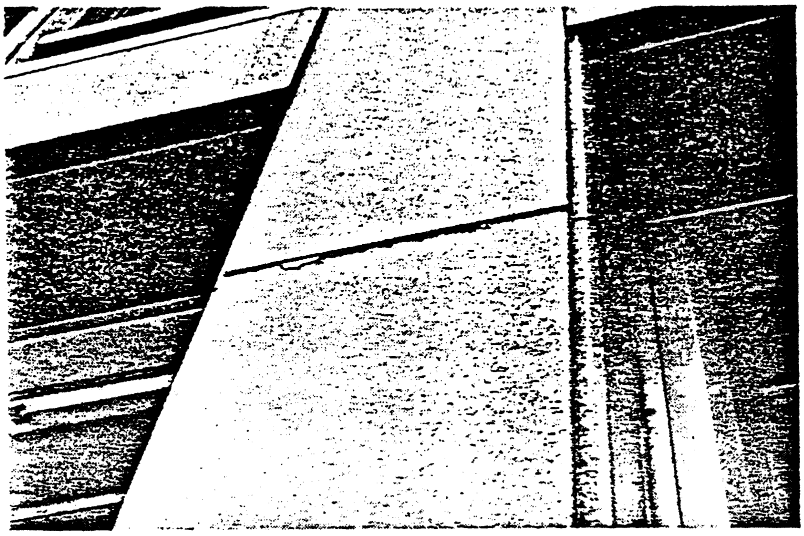

Figure 6. Spalling and displacement of column cladding.

CONCLUSION

Air exfiltration through walls and air interchange between exterior wall spaces and a building in winter are a principal source of water leading to damages due to wetting and frost action in both old and new buildings. Good wall design requires adequate restriction to both types of air movement, not only in the building as originally constructed but throughout its intended life.

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