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STACK EFFECT IN BUILDINGS

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Stack effect in buildings is the same as stack effect in a chimney. The draft produced in a chimney depends on the difference between the temperatures of the flue gas and the outside air as well as on the chimney height. During cold weather similar action occurs in buildings, although the inside-to-outside air temperature difference is much less. Even for one- or two-storey houses the stack effect in winter is sufficient to affect certain aspects of air leakage significantly; and in very tall buildings it can lead to pressure differences as great as 1 in. of water across exterior walls.

This Digest discusses the nature of stack action, the distribution of air pressures across a building enclosure and its interior separations that stack action causes, and some of the implications of the resulting air flow patterns. Air pressure differences across building components are also caused by wind action and the operation of mechanical air supply and exhaust systems (CBD 23). Problems caused by air leakage in buildings have been discussed in other Digests (CBD 25, 42, and 72).

Stack Effect

Stack effect can be explained with the aid of Figure 1(a), which represents a building with no internal separations, a single opening at the bottom, and an air temperature inside greater than that outside. The graph shows the variations with height of the absolute air pressures; under steady temperature conditions pressures inside and outside are equal at the level of the opening. The absolute pressures decrease with height because of the reduction of the total weight (per unit area) of the air above. This phenomenon of decreasing air pressures with height is widely experienced and is noticeable in the ear discomfort it causes during rapid changes in elevation, as when travelling on non-pressurized aircraft.

Figure 1(a) indicates that the outside air is denser than that inside, so that reduction in pressure with height is more rapid outside; and the absolute pressure inside is greater than that outside at all levels above the opening. This difference in pressure is the stack effect. It acts across the walls of the building and is equal to the horizontal distance between the lines representing the inside and outside pressures; the maximum value occurs at the top and is the stack effect for the total height of the building. Stack effect can be calculated from the following relation:

$$p_s = 0.52\ PH \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \quad (1)$$

where p_s = total pressure difference caused by stack effect, in. of water

P = ambient pressure, psia

H = building height, ft

T_o = absolute temperature, outside, °F

T_i = absolute temperature, inside, °F

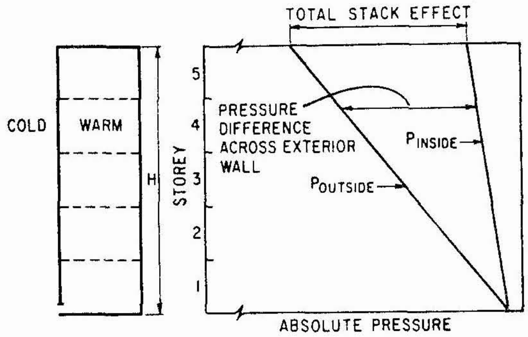
As an example, the total stack effect for a building 50 storeys high and with an outside air temperature of −25°F is approximately 2 in. of water (see CBD 23, Table III).

If the opening in Figure 1(a) had been at the top of the building, absolute pressures inside and outside would have been equal at the top; the pressure inside would have been less than that outside at all lower levels; and the maximum pressure difference across the walls of the enclosure at the bottom would have been equal in magnitude but opposite in direction to that at the top.

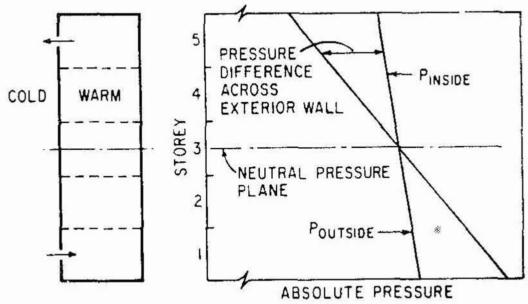
Openings through which air can leak occur in the walls of buildings at various levels. Figure 1(b) represents a heated building with no internal separations and openings of equal size in the exterior wall, top and bottom. The air in the building is warmer and therefore lighter than that outside, so that it tends to rise and escape through the upper opening while colder outside air comes in through the lower opening to replace it. The pressure difference required to cause flow through the openings is the stack effect. As air flow takes place from high to low pressure, the pressure outside must be higher than that inside at the bottom and lower than that inside at the top. Because the openings at the top and bottom are of equal size they impose an equal resistance to flow. The pressure differences across them are therefore of equal magnitude.

The inside and outside pressures required to fulfil these conditions are as illustrated in Figure 1(b). Lines representing the absolute pressures cross at mid-height, indicating that there is no pressure difference across the exterior wall; this level, where the inside and outside pressures are equal, is called the neutral zone or neutral pressure plane. In Figure 1(a) the neutral pressure plane is at the level of the bottom opening. The pressure difference across the exterior wall increases in proportion to the distance from it. As the temperature difference between inside and outside increases, the difference in the slopes of the lines representing inside and outside pressures increases, and the pressure difference across the exterior wall increases. The total pressure difference caused by stack effect, which can be calculated from equation (1), is the sum of the pressure differences across the exterior walls at top and bottom.

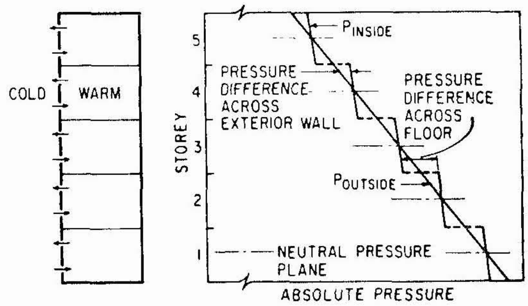
Leakage openings in the exterior walls of a building are not always distributed uniformly from bottom to top, but the in-flow always equals the out-flow. If the openings at the bottom were larger than those at the top, and therefore imposed a smaller resistance to flow,



(Ia) NO INTERNAL PARTITION
SINGLE OPENING AT THE BOTTOM



(Ib) NO INTERNAL PARTITION
EQUAL OPENINGS AT TOP AND BOTTOM



(Ic) COMPLETE ISOLATION OF EACH STOREY WITH EQUAL OPENINGS TOP AND BOTTOM

Figure 1 Stack effect for simple enclosures.

the pressure difference across the bottom would be less than that across the top. This would be equivalent to a shift of the inside pressure line to the right and a lowering of the neutral plane. The extreme situation, with the bottom openings very large in relation to those at the top, is represented by the pressure pattern shown in Figure 1(a).

Figure 1(c) represents a building with perfectly air-tight separations at each floor level, so that there can be no flow of air between stories; and with openings of equal size in the exterior wall of each storey, top and bottom. Each storey thus acts independently, its own stack effect unaffected by that of another level. There is a tendency for air to flow in at the bottom and out at the top of each storey, with a neutral pressure plane between. The sum of the pressure differences across the exterior walls at the top and bottom of any storey, therefore, is equal to the stack effect for that storey. This is equivalent to the pressure difference acting across each floor, and is represented by the horizontal line at each floor level. The total stack effect for the total building height is the same as that in Figure 1(b) and is equal to the sum of the pressure differences across the floors, plus the pressure difference across the exterior walls at top and bottom of the building.

In reality, multi-storey buildings are not completely open inside, as represented in Figure 1(b), nor are the separations between stories completely air tight (Figure 1(c)). There are passages for air to flow directly through the floors, and there are stairwells, elevators and other service shafts that penetrate the floors and provide passages for air to flow between stories. This is illustrated in Figure 2, which represents a heated building with a uniform distribution of openings in the exterior

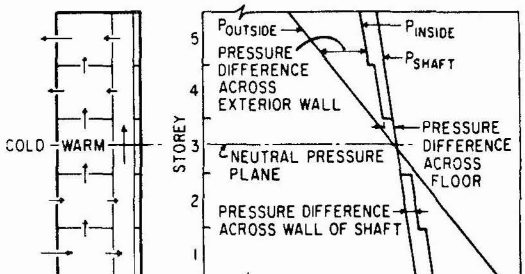


Figure 2 Stack effect for idealized building.

wall, through each floor, and into the vertical shaft at each storey.

The general pattern of air flow is the same as that in Figure 1(b). Air comes into the building at the bottom, flows upwards through vertical shafts and openings in the floors, and passes out through openings in the upper exterior wall. Between floors the slope of the line representing the inside pressure is the same as that in Figure 1(b), but there is a discontinuity at each floor, as in Figure 1(c), that represents the pressure difference across it. The total stack effect for the building remains the same as before, but some of the total pressure difference is required to maintain the air flow through the openings in the floors and vertical shafts. The pressure difference across the exterior wall at any level is therefore less than if there were no resistance to flow within the building.

Figure 2 also indicates the pattern of pressure difference and air flow for the vertical shaft. It is assumed that there is no significant resistance to flow within the shaft, so that the line representing pressure has a uniform slope determined by the density of inside air for the building as a whole (as in Figure 1(b)). The horizontal distance between this line and that for the pressure within the building proper represents the pressure difference across the wall of the shaft and any openings it contains. With a uniform resistance to air flow across the floors and a uniform resistance to flow into the shaft at each floor level, air enters the shaft at lower levels and leaves it at higher levels in a symmetrical pattern. The neutral pressure plane for the shaft with respect to adjacent spaces in the building occurs near mid-height. The pressure difference across the wall of the shaft is maximum at the top and bottom and the change in this pressure difference from floor to floor corresponds to the pressure difference across the intervening floor. Thus the sum of pressure differences across the shaft wall at the bottom and top is equal to the sum of the pressure differences across all the floors in the building.

The total stack effect for the building is equal to the sum of the pressure differences across the exterior wall at bottom and top plus the pressure differences across all the floors. As the resistance to flow imposed by separations within the building increases, the pressure differences across floors and walls of vertical shafts increase and the pressure differences across the exterior walls decrease.

Air flow induced by stack effect within a real building occurs through each path illustrated in Figure 2. As the height and number of floors increase, however, the total resistance of the flow path through openings in the floors increases more rapidly than that through the vertical shafts; thus with high buildings, upward air flow occurs mainly through the vertical shafts.

Air Flow Effects

Some of the effects of the general pattern of flow and pressure differences resulting from stack effect in a heated building, as illustrated in Figure 2, can be usefully reviewed. It may be seen that infiltration occurs below the neutral pressure plane and exfiltration above it. There is a general upward movement of air inside the building, with air flowing into vertical shafts from the lower floors and out to the upper ones.

This general pattern causes a variation in the heating and humidification load from floor to floor, and therefore has implications for the maintenance of uniform temperatures and humidities throughout the building. It is also a factor in the spread of odours and other contaminants. If fire occurs in lower floors there is a tendency for smoke to move to upper floors via the vertical shaft, and for stairwells and corridors to become smokefilled. This pattern of smoke movement induced by stack effect must be regarded as one of the major problems in providing for fire safety in high buildings.

Air entering through exterior walls at the lower levels is a source of cold drafts as well as dust and other contaminants. It is particularly troublesome near entrances. Air exfiltrating through the roof of exterior wall construction at the upper levels can give rise to damage from condensation when the water vapour it contains is cooled below its dew-point temperature inside the structure. The extent of condensation depends on the quantity of air flow, its initial moisture content, and the reduction in temperature it undergoes in passing through the building components. In general, moisture problems due to exfiltration will increase with increasing building height, decreasing average winter temperature, and increasing building humidity.

During the summer, when the outside air temperature is higher than that inside, the pattern of pressure differences and air flow is the reverse of that shown in Figure 2. Infiltration occurs through the exterior walls at the upper levels and exfiltration at lower levels, with air flowing downward within the building. The stack effect is, however, much less than under winter conditions because of the smaller inside-to-outside air temperature difference, and its importance is reduced correspondingly.

Summary

The total pressure difference acting on a building as a result of stack action depends upon building height and the difference between temperatures inside and outside. It cannot be avoided, but the way in which it is distributed across the building enclosure and interior separations can be modified through design because it depends upon the relative resistances to flow presented by the building components and the way in which they are distributed in the flow path.

Air movement caused by stack action has many important implications related to the functional adequacy of buildings that should be recognized in both their design and operation. This Digest provides a basis for understanding the nature of stack action and some of the problems it may present. Some of the choices available to the designer in providing for its control will be the subject of a future Digest.

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