Stack effect and building design

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Stack Effect and Building Design

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Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Previous discussions (**CBD 104**) of the mechanism of stack action in buildings have provided a useful background for this Digest. They emphasized that the total pressure difference acting on a building as a result of stack effect depends entirely upon building height and the difference between temperatures inside and outside; and that although stack effect cannot be avoided its distribution across the building enclosure and interior separations can be modified through design.

This Digest discusses air tightness and the distribution of pressure differences resulting from stack effect in buildings as they are designed at present. It also discusses ways in which pressure differences and air flow may be modified by varying air tightness characteristics or by the operation of mechanical air supply and exhaust systems.

Current Construction

Figure 1 shows the pattern of pressures and air flow caused by stack effect for an idealized building with uniform distribution of openings in the exterior wall, through each floor, and into the shaft at each storey. **CBD 104** indicated that the distribution of the total pressure difference from stack effect depends upon the air tightness of the exterior walls of the building in relation to that from floor to floor. Measurements made on several multi-storey buildings have shown that up to 80 per cent of the total pressure difference is taken across the outside walls, and that the remainder is distributed across the various interior separations. This indicates that with present construction there is a relatively low resistance to air flow from floor to floor compared with that through the exterior wall. The level of the neutral pressure plane, which depends upon vertical distribution of the openings through which air flows into, through, and out of buildings, is generally near mid-height.

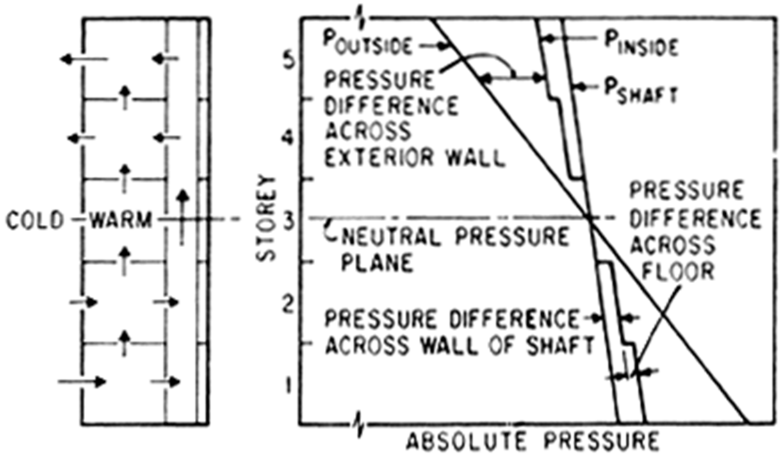

Figure 1. Stack effect for idealized building.

For a uniform distribution of openings, as in Figure 1, pressure differences from stack effect can be estimated. For example, with 80 per cent of the total pressure difference taken across the outside walls and a neutral pressure plane at mid-height, the pressure drop at the entrance is equal to 40 per cent of the total. Similarly, the pressure difference across the walls of vertical shafts at the first floor level is equal to 10 per cent of the total.

Absolute values of these pressure differences for specific conditions can be estimated from Figure 2. For example, the total pressure difference from stack effect for a building 600 ft high at a temperature difference of 100 F deg is about 2 in. of water. With the distribution of pressures referred to above, the pressure difference across the entrance is about 0.8 in. of water and that across the vertical shaft at the ground floor level, 0.2 in. of water. When the pressure difference across a 20-sq-ft door exceeds 0.6 in. of water, the force required to open it is greater than can be applied by the average adult. In order to reduce the opening forces required and to reduce air infiltration, it is common practice to incorporate vestibule and revolving door entrances in high buildings. A vestibule divides the pressure difference across the entrance, so that each bank of doors sustains only half the total. It might be noted that exterior doors at the top of buildings leading to roof areas sustain pressure differences similar to those at building entrances, but acting in the opposite direction.

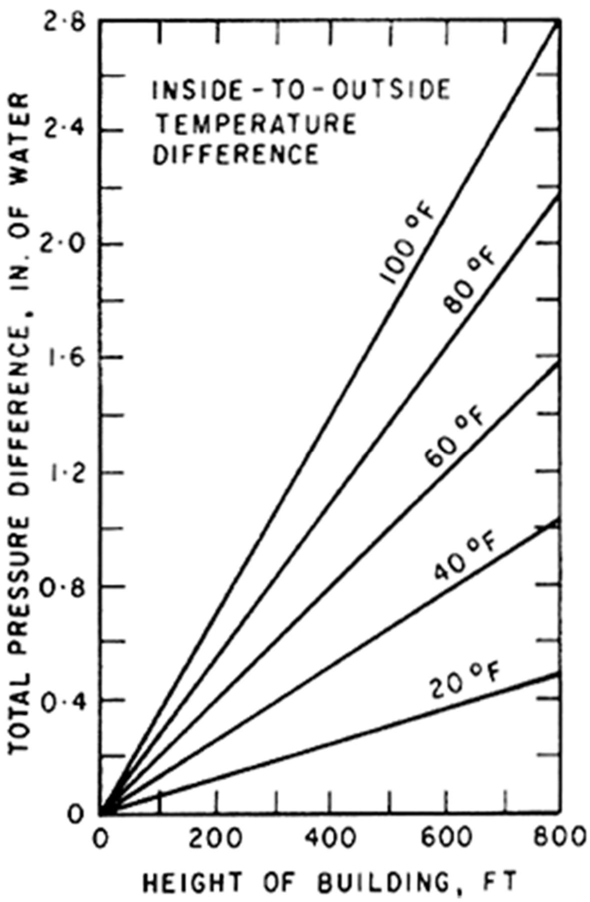

Figure 2. Total pressure difference caused by stack effect.

Operating difficulties with elevator or stairwell doors are not usually encountered at pressure differences of 0.2 in. of water; noise caused by air flow through cracks may, however, be perceptible with some doors at even lower pressure differences. Greater pressure differences do occur across interior doors of some buildings when they lead to a storey that has a substantial opening to outside. This effect is greatest when the storey is near the top or bottom of the building. For example, exterior walls of entrance storeys often have more leakage openings than storeys above, and thus sustain a smaller proportion of the total stack effect than is indicated in Figure 1.

An extreme case is shown in Figure 3, which illustrates pressure distribution when there is a very large opening to outside on the entrance floor; this condition would be approximated with all entrance doors held open. The pressure in the entrance floor is then the same as that outside, and this imposes a greater pressure difference across openings into the vertical shafts (on that storey), and across the floor separations above. A similar effect would occur in an upper storey with an outside wall that offered little resistance to air flow; there would be a reduced pressure difference across the exterior walls and an increased pressure drop across the floor slab and walls of vertical shafts at this level. This sometimes occurs when a mechanical equipment room is located at or near the top of a building. Where the tightness of the exterior enclosure of some storeys cannot be assured, it may be necessary to incorporate vestibule entrances around elevators and stairwells to cope with the increased pressure differences across the interior separations.

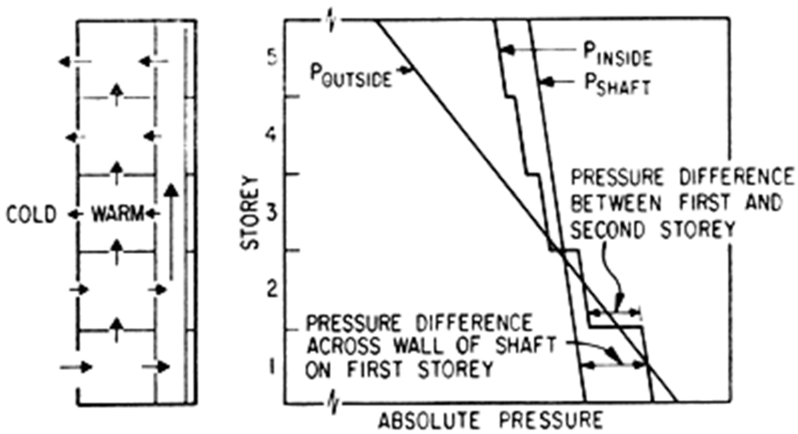

Figure 3. Stack effect with equal pressurization of each floor.

Increasing Building Tightness

Many of the problems caused by stack effect in buildings could be alleviated by increasing the air tightness of the building enclosure and interior separations. Although the tightness of the exterior of present constructions is greater than that of interior separations, recent measurements of over-all air leakage rates indicate that wall leakage values are considerably higher than would be assumed from laboratory measurements on components. There appear, therefore, to be opportunities for increasing the air tightness of the building enclosure. Because most of the total pressure difference is already taken across the enclosure, a further increase in air tightness would not cause a major shift in the distribution of pressure differences; but it would result in a decrease in the rate of air infiltration, exfiltration, and upward flow within the building.

A reduction of air leakage from stack effect could also be achieved by increasing the resistance to flow through interior separations, without any change in the tightness of the exterior. It would alter the distribution of the pressure difference illustrated in Figure 1, shifting the pressure inside the building closer to that outside, with a consequent increase in the shaft wall pressure difference and a decrease in the outside wall pressure difference. With the tightness of interior separations substantially greater than that of the exterior, most of the stack effect would be taken across the interior elements (see **CBD 104**, Figure 1c); and large pressure differences would then be imposed across the walls of shafts passing through several storeys. Pressure differences across the exterior walls would be minimized. Altering the tightness of buildings in this way presents some difficult problems in design and construction, both in achieving the increased tightness and in coping with the resulting increase in pressure differences between storeys and across walls of vertical shafts.

Special consideration of air tightness requirements for interior separations may be needed in relation to the control of smoke movement in the event of fire, when the air tightness of the exterior may not be assured; for example, entrances and stairwell doors may be open, and windows broken. The problem of designing for smoke control is a complex one involving a number of factors which go beyond the scope of this Digest.

Effect of Ventilation System

Pressures inside buildings and air leakage patterns are affected by any imbalance of the air supplied and exhausted by air handling systems. These systems are sometimes designed and operated to provide an excess of supply air and thus to pressurize the building and reduce infiltration, particularly that resulting from stack effect at lower levels of multi-storey buildings during cold weather. The pressurization that results from a given excess of supply air will depend upon the tightness of the building enclosure.

If the excess air supply is introduced uniformly at all levels, the pressure difference across exterior walls at lower levels (causing infiltration) will decrease; that at upper levels (causing exfiltration) will increase by a similar amount. This is shown in Figure 4, which indicates the effect of uniform pressurization of the idealized building of Figure 1 to the point where inside and outside pressures are equal at the first floor level.

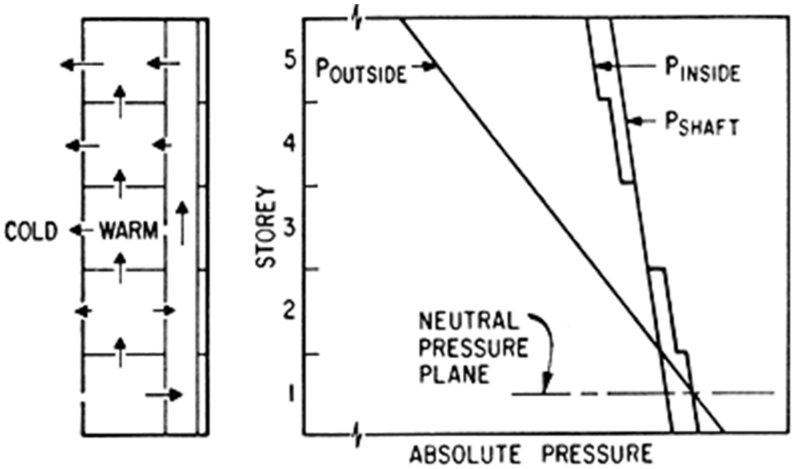

Figure 4. Stack effect with equal pressurization of each floor.

It will be seen that pressurization does not eliminate stack effect, but that it alters the distribution of pressure differences across the exterior walls. The lines representing the pressure distribution inside the building and vertical shaft are displaced to the right; pressure differences between storeys and across walls of vertical shafts, and the resulting upward flow of air within the building, are essentially the same as with no pressurization (Figure 1). Although infiltration through exterior walls is minimized, exfiltration is greatly increased; and there is a penalty in higher heating costs because it is necessary to heat the additional outdoor air that must be brought in to provide the pressurization. In the example, the total required outside air supply is equivalent to about three times the air infiltration when there is no pressurization. The advantage of tight exterior walls is therefore apparent, particularly when pressurization is required.

Large pressure differences across shafts and floor separations may sometimes result when there are differences between floors in the imbalance of supply and exhaust air; these may be either intentional or accidental. For example, the pressure pattern shown in Figure 3 is the same as that which would result if only the ground floor were pressurized sufficiently to overcome the normal pressure difference across the entrance because of stack effect. Under this condition there would be no leakage through the entrance, but the total excess supply air required on the entrance floor would be about equal to the total air infiltration without pressurization (Figure 1); infiltration on other floors would be about one third of the original total, so that the penalty in higher heating costs would be considerably less than with uniform pressurization.

Again, stack effect is not eliminated; but the distribution of pressure differences across both exterior and interior separations is altered. The normal upward flow of air in the building is augmented by that supplied to the first floor. Pressure differences across exterior walls at upper levels are increased only slightly, but the pressure differences across the lower floor separations and across stairwell and elevator doors at the ground floor level are substantially increased. In high buildings, these pressure differences would be excessive unless additional separations, such as vestibule entrances, were incorporated around the shafts.

In theory, a mechanical ventilation system could be designed to minimize pressure difference across the exterior wall of each storey by providing an excess of air supply to lower floors and an excess of exhaust from upper ones (see **CBD 104**, Figure 1c). Under this condition, all of the pressure difference from stack effect would be taken across the floor separations and the walls of any intervening vertical shafts, and upward air flow through the building would be very large unless the air tightness from floor to floor were greatly increased. Such a system would not, therefore, be practicable without major changes in building design.

An excess of supply or exhaust air is sometimes used to maintain a space at a pressure either above or below surrounding areas in order to control the movement of contaminants to or from the space. This technique may have some application in the control of smoke movement in buildings, either to maintain some spaces smoke free, or to minimize smoke transfer from a fire zone to other occupied parts of the building. The design of such a system would require careful consideration of the air tightness characteristics of the spaces under fire conditions, and integration with the overall fire safety plan for the building.

Summary

Stack effect in buildings cannot be avoided, but it can be modified by design if its nature is recognized. In current buildings a large part of the pressure difference caused by stack effect is taken across the exterior walls at upper and lower levels; the wall and its components and entrances must therefore be designed to accommodate it if serious problems are to be avoided. The pressure differences across interior separations are generally smaller, but they can be excessive across entrances to vertical shafts under certain conditions. Many current buildings present a relatively low resistance to the air flow induced by stack effect, and many of the associated problems could be alleviated by increasing the air tightness of exterior enclosures and interior separations.

There are possibilities for modifying the distribution of pressures and air flow patterns resulting from stack effect through changes in building design and construction. Distribution can also be modified through the operation of mechanical air handling systems to provide an imbalance of supply or exhaust. This technique is best considered at an early stage in planning so that its effects on pressures and air leakage can be considered in the design of the structure.