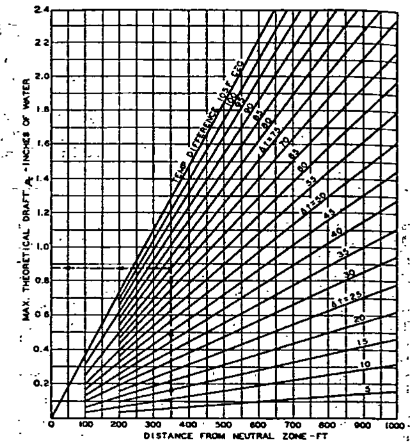
faces depend not only on roof shape and height above ground, but also vary with wind angle and location on the roof with respect to the leading edge or ridge. At leading edges of flat or low-pitched roofs (up to 30 deg pitch) negative pressures of -0.8 to $-1.0\ p_v$ may occur, while pressures over the remaining areas may have values of -0.2 to $-0.8\ p_v$. Pressures may have values of $+0.2$ or $+0.3\ p_v$ on the windward side of high pitched roofs, while leeward side pressures may be -0.5 to $-0.7\ p_v$.

In the prediction of rates of infiltration or natural ventilation, pressure differences across the walls or roof of the building are required, and these depend on internal as well as external pressures. Pressures inside buildings due to wind action alone will depend on the resistances of cracks and openings and their location with respect to the wind direction. In large buildings the tightness of internal space separations also may be a factor. If the openings are uniformly distributed around the walls of the building, inside pressures will usually be within plus or minus $0.2\ p_v$. If openings on the windward side predominate, inside pressures up to $+0.8\ p_v$ may occur, approaching the positive values on the outside. Conversely, if openings on the leeward side predominate, inside pressures may have negative values of 0.2 to 0.4 p_v or greater.

The selection of appropriate wind velocities for purposes of calculating pressure differences across the building enclosure due to wind action, is not straightforward since the relationship between recorded wind and wind at the building site varies and is difficult to establish. Data on wind is usually based on records obtained at meteorological stations, often airports, where anemometers are usually on top of buildings in relatively open country. Buildings are located within the surface boundary layer of the earth, where there is a significant increase in velocity with height. Furthermore, the relationship between velocity and height depends strongly on the surface roughness as influenced by the type of terrain; whether flat open country or water, wooded country or suburbs, or large city buildings. In addition to the problem of translating measured velocities into those at the building site, there is the question of the effect of the vertical velocity gradient on the pressure distribution, especially around tall buildings. Some measurements[1] suggest that the variation of static pressures with height at the surface of buildings is much less than the variations in the velocity pressures of the oncoming flow. Measurements on the Empire State Building[2] show little difference between pressures at the 36th and 75th floor levels. Shielding of one building by another results in significant reductions in effective wind velocities. At street level among large buildings wind directions and velocities may bear little relation to those measured at the nearest weather station.[3] In general, the velocity of the wind acting on the surface of a building is entirely too complicated to be represented by anything that is rational.

TEMPERATURE DIFFERENCE FORCES

When the temperature in a building or room is different from that outside, pressure differences between inside and outside occur as a result of differences in air density, that is, chimney or stack effect. When the inside temperature is higher than outside, this chimney effect produces a negative inside pressure and inward flow of air at lower levels, and a positive inside pressure and outward flow at higher levels. The reverse occurs when the inside temperature is lower than outside. At some level, with temperature forces alone acting, there is a neutral zone or plane where there is no pressure difference between inside and out.[4] At any other level the pressure difference depends on the distance from the neutral zone and the difference between the densities of inside and outside air.



Based on average indoor air at 75 F, 50 percent RH, standard atmospheric pressure 29.921 in. Hg.

Fig. 2 .... Theoretical Draft in Buildings Due to Chimney Effect

This can be expressed:

$$p_c = 0.52Ph\left(\frac{1}{T_o} - \frac{1}{T_i}\right) \qquad (2)$$

where

p_c = theoretical pressure difference across enclosure due to chimney effect, inches of water.

P = absolute pressure, pounds per square inch.

h = distance from neutral zone, or effective chimney height, feet.

T_o = absolute temperature outside, Fahrenheit.

T_i = absolute temperature inside, Fahrenheit.

This relationship does not account for pressure losses between the neutral zone and other levels due to resistance to flow within the structure. Values of p_c for any effective chimney height and indoor to outdoor temperature difference can be obtained from Fig. 2.

The level of the neutral zone depends on the vertical distribution and resistances to air flow of openings through which inflow and outflow can occur. For example, if there is only one opening, or if one opening is extremely large relative to the others, the neutral zone will be at or near the center of the opening. If the openings are uniformly distributed vertically, the neutral zone will be at the mid-height of the enclosure. If there are no space separations, or if their resistance to flow is small (the usual case), a building acts as a single chimney and the pressure at any level in the building is constant. If the spaces are isolated from one another, each has a separate chimney effect and neutral zone independent of the others. In most cases there is some degree of interconnection of spaces, and the pressures within a space are affected by the action of the building as a whole. Thus, the vertical distribution of pressure differences across the walls of a building depends on the resistance to flow of horizontal and vertical space separations as well as the vertical distribution of openings.

With only temperature forces acting, the calculation of the probable level of the neutral zone for simple enclosures with openings of known air flow characteristics is straightforward. In complex buildings, however, the effects of internal space separations, stairwells, elevator shafts, utility ducts, chimneys, vents, and mechanical air supply and exhaust systems are difficult to evaluate. Chimneys represent openings at or above the roof and, therefore, have the effect of increasing the height of the neutral zone. The effect of a chimney on the level of the neutral zone is especially important in houses or small buildings where the exhaust from the chimney represents a substantial proportion of the exfiltration. Exhaust systems also increase the height of the neutral zone, while air supply systems have the opposite effect.

Available data on the levels of neutral zones in various kinds of buildings is extremely limited. The neutral zone in a 47-story office building, on which measurements were made in 1934,[5] was at or somewhat below mid-height over a range of outdoor temperatures. Similar measurements on a 40-story office building, reported in 1937,[6] indicate that the neutral zone was generally around the 24th floor, an elevation about 60 percent of the height of the structure. In both these investigations the pressure differences above and below the level of the neutral zone were somewhat less than would be calculated from Equation 2, probably due to the pressure losses required to maintain the upward flow in the building. More recent measurements[7] of pressure differences across entrances in tall buildings indicate that the apparent level of the neutral zone is 0.7 of the total building height for conventional buildings. In one unusually tight modern building with pneumatically sealed windows, the apparent level of the neutral zone was 0.3 of the total height.

It would appear from these results and other observations[7] that vertical openings, such as stairwells, elevators and other utility shafts in tall buildings, often are not well sealed and that pressure differences due to chimney action result, to a large degree from action of the building as a whole. It is clear from Equation 2 that pressure differences due to chimney effect would be greatly reduced if the sealing of vertical openings were made really effective.

Measurements[8] on houses indicate that the neutral zone is likely to be well above mid-height and that the effect of the chimney in raising the level of the neutral zone increases with decreasing outdoor temperature.

COMBINED FORCES

The pattern of pressure differences across a building enclosure depends on the magnitude of all acting pressure forces and the distribution of openings into and within the building. In an actual building, since the relative magnitude of the forces is continually changing, the pressure pattern changes accordingly. In design calculations the limiting conditions, either minimum or maximum, are usually required. For these cases one force may dominate so that it may be necessary to determine only the relative magnitude of air flow induced by one or more forces acting singly. In other instances, particularly in tall buildings, it may be necessary to consider pressure forces in combination in order to arrive at a rational design.

Each building presents a unique problem, but the manner in which the pressure forces act can be considered qualitatively with reference to Fig. 3, which represents the distribution of indoor and outdoor pressures with height for a building in which openings of equivalent area are equally distributed above and below mid-height and where there is no significant resistance inside to flow from top to bottom. The slopes of the lines are functions of the densities of indoor and outdoor air. In Fig. 3(a), with inside warmer than outside and pressure differences due to stack action alone, the neutral zone is at mid-height with inflow through all openings below and outflow through all openings above. The effect of a chimney or mechanical exhaust from the building would be to shift the inside pressure line to the left, raising the level of the neutral zone. An excess of supply air over exhaust would have the opposite effect. Fig. 3(b) shows pressure differences due to wind alone with the magnitude of wind effect on windward and leeward sides equal but opposite in sign.

Fig. 3(c) represents the condition where the wind forces illustrated in Fig. 3(b) have just balanced the temperature difference forces with no pressure difference at the top on the windward sides or at the bottom on the leeward sides. Thus the total flow is only slightly more or less than with stack action alone. Beyond this point, as the relative magnitude of pressure differences due to wind increases, the lines representing windward and leeward pressures move to the right and left, and the total flow becomes increasingly independent on wind, although the differences in pressure with height due to temperature may result in significant variations in flow with

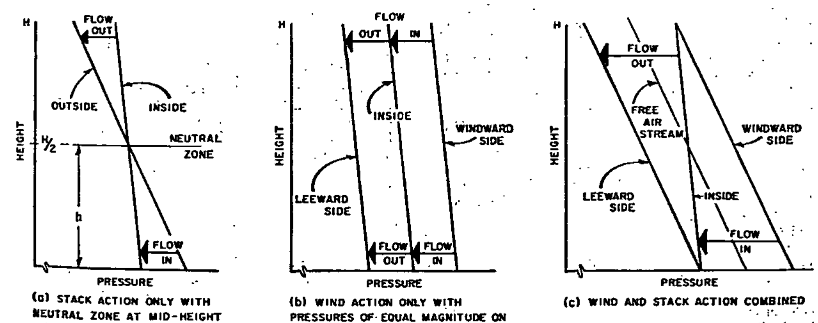


Fig. 3 .... Distribution of Inside and Outside Pressures Over the Height of a Building