

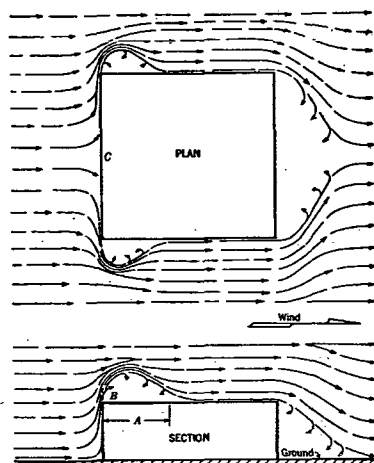


Fig. 2.... The Jump of Wind from Windward Face of Building. (A)—Length of Suction Area; B—Point of Maximum Intensity of Suction; C—Point of Maximum Pressure)

slightly greater than that of a square-edged orifice. If the openings are not advantageously placed with respect to the wind, the flow per unit area of the openings will be less and, if unusually well placed, the flow will be slightly more than that given by the formula. Inlets should be placed to face directly into the prevailing wind, while outlets should be placed in one of the five places listed:

1. On the side of the building directly opposite the direction of the prevailing wind.
2. On the roof in the low pressure area caused by the jump of the wind (see Fig. 2).
3. On the sides adjacent to the windward face where low pressure areas occur.
4. In a monitor on the side opposite from the wind.
5. In roof ventilators or stacks.

TEMPERATURE DIFFERENCE FORCES¹⁰

The stack effect produced within a building, when the outdoor temperature is lower than the indoor temperature, is due to the difference in weight of the warm column of air within the building and cooler air outdoors. The flow due to stack effect is proportional to the square root of the draft head, or approximately

$$Q = 9.4A \sqrt{h(t_i - t_o)} \quad (4)$$

where

- Q = air flow, cubic feet per minute.
 A = free area of inlets or outlets (assumed equal), square feet.
 h = height from inlets to outlets, feet.

- t_i = average temperature of indoor air in height h , Fahrenheit.
 t_o = temperature of outdoor air, Fahrenheit.
 9.4 = constant of proportionality, including a value of 65 percent for effectiveness of openings. This should be reduced to 50 percent (constant = 7.2) if conditions are not favorable.

HEAT REMOVAL

In problems of heat removal, knowing the amount of heat to be removed and having selected a desirable temperature difference, the amount of air to be passed through the building per minute, to maintain this temperature difference, can be determined by means of Equation 5.

$$Q = \frac{H}{C_p \times \rho \times 60(t_i - t_o)} = \frac{H}{1.08(t_i - t_o)} \quad (5)$$

where

- Q = air removed, cubic feet per minute.
 H = heat removed, Btu per hour.
 C_p = specific heat of air at constant pressure, 0.24.
 ρ = density of standard air, 0.075 pounds per cubic foot.
 $t_i - t_o$ = indoor-outdoor temperature differences, Fahrenheit.

EFFECT OF UNEQUAL OPENINGS

The largest flow per unit area of openings is obtained when inlets and outlets are equal, and the preceding equations are based on this condition. Increasing outlets over inlets, or vice-versa, will increase the air flow, but not in proportion to the added area. When solving problems having an unequal distribution of openings, use the smaller area, either inlet or outlet, in the equations, and add the increase as determined from Fig. 3.

COMBINED FORCES OF WIND AND TEMPERATURE

Equations have already been given for determining the air flow due to temperature difference and wind. It must be remembered that when both forces are acting together, even without interference, the resulting air flow is not equal to the sum of the two estimated quantities. The flow

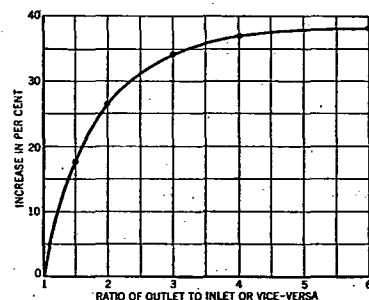


Fig. 3.... Increase in Flow Caused by Excess of One Opening Over Another

Infiltration and Ventilation

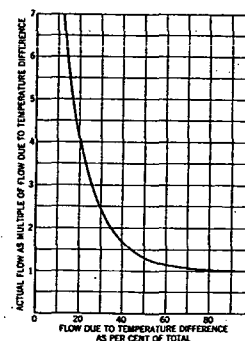


Fig. 4.... Determination of Flow Caused by Combined Forces of Wind and Temperature Difference

through any opening is proportional to the square root of the sum of the heads acting on that opening.

When the two heads are about equal in value, and the ventilating openings are operated so as to coordinate them, the total air flow through the building is about 10 percent greater than that produced by either head acting independently under conditions ideal to it. This percentage decreases rapidly as one head increases over the other. The effect of the larger head will predominate.

The wind velocity and direction, the outdoor temperature, or the indoor distribution, cannot be predicted with certainty, and refinement in calculations is not justified; consequently, a simplified method can be used. This may be done by using the equations and calculating the flows produced by each force separately, under conditions of openings best suited for coordination of the forces. Then, by determining the ratio of the flow produced by temperature difference to the sum of the two flows, the actual flow due to the combined forces can be approximated from Fig. 4.

Example 1: Assume a drop forge shop, 200 ft long, 100 ft wide, and 30 ft high. The cubical content is 600,000 cu ft, and the height of the air outlet over that of the inlet is 30 ft. Oil fuel of 18,000 Btu per lb is used in this shop at the rate of 15 gph (7.75 lb per gal). Desired summer temperature difference is 10 deg, and the prevailing wind is 8 mph perpendicular to the long dimension. What is the necessary area for the inlets and outlets, and what is the rate of air flow through the building?

Solution for Temperature Difference Only: The heat $H = 15 \times 7.75 \times 18,000 = 2,092,500$ Btu per hr. By Equation 5, the air flow required to remove this heat with an average temperature difference of 10 deg is

$$Q = \frac{H}{1.08(t_i - t_o)} = \frac{2,092,500}{1.08 \times 10} = 193,750 \text{ cfm.}$$

This is equal to about 20 air changes per hour. From Equation 4, the inlet (or outlet) opening area should be

$$A = \frac{Q}{9.4 \sqrt{h(t_i - t_o)}} = \frac{193,750}{9.4 \sqrt{30 \times 10}} = 1190 \text{ sq ft}$$

The flow per square foot of inlet or outlet would be $193,750 \div 1190 = 162.5$ cfm, with all windows open.

Solution for Wind Only: With 1,190 sq ft of inlet openings distributed around the side walls, there will be about 400 sq ft in each long side and 195 sq ft in each end. The outlet area will be equally distributed on the two sides of the monitor, or 595 sq ft on each side. With the wind perpendicular to the long side, there will be 400 sq ft of opening in its path for inflow, and 595 in the lee side of the monitor for outflow with the windward side closed. The air flow, as calculated by Equation 3, will be:

$$Q = 0.60 \times 400 \times 704 = 168,960 \text{ cfm.}$$

This gives 16.9 air changes per hour, which should be more than ample when there is no heat to be removed.

Solution for Combined Heads: Since the windward side of the monitor is closed when the wind is blowing, the flow due to temperature difference must be calculated for this condition, using Fig. 3. This chart shows that, when inlets are twice the size of the outlets, in this case 1,190 sq ft in the side walls and 595 sq ft in the monitor, the flow will be increased 26.5 percent over that produced by equal openings. Using the smaller opening and the flow per square foot obtained previously, the calculated amount for this condition will be

$$595 \times 163 \times 1.265 = 122,700 \text{ cfm.}$$

Adding the two computed flows:

Temperature Difference	= 122,700	= 42 percent.
Wind	= 168,960	= 58 percent.
Total	291,660	= 100 percent.

From Fig. 4 it is determined that, when the flow due to temperature difference is 42 percent of the total, the actual flow due to the combined forces will be about 1.5 times that calculated for temperature difference alone, or 196,300 cfm.

The original flow due to temperature difference alone was 193,750 cfm with all openings in use. The effect of the wind is to increase this to 196,300 cfm, even though half of the outlets are closed.

A factor of judgment is necessary in the location of the openings in a building, especially those in the roof, where heat, smoke, and fumes are to be removed. Usually, windward monitor openings should be closed, but if the wind is low enough for the temperature head to overcome it, all windows may be opened.

TYPES OF OPENINGS

Types of openings may be classified as: (1) windows, doors, monitor openings, and skylights; (2) roof ventilators; (3) stacks connecting to registers; and (4) specially designed inlet or outlet openings. The various types and principles of operation are discussed in following paragraphs.

Windows, Doors, and Skylights

Windows have the advantage of transmitting light, as well as providing ventilating area, when open. Their movable parts are arranged to open in various ways; they may open by sliding either vertically or horizontally, by tilting on horizontal pivots at or near the center, or by swinging on pivots at the top, bottom, or side. Regardless of their design, the air flow per square foot of opening may be considered to be the same under the same conditions. The type of pivoting should receive consideration from the standpoint of weather protection, and certain types may be advantageous in controlling the distribution of incoming air. Deflectors are sometimes used for the same purpose and should be considered a part of the ventilation system.

Roof Ventilators

The function of a roof ventilator is to provide a storm and weatherproof air outlet. They are actuated by the same