

Fig. 9 .... Determination of Flow Caused by Combined Forces of Wind and Temperature Difference

ently 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. 9.

Example 3: 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 4, 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 6, 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 sq ft in the lee side of the monitor for outflow with the windward side closed. The air flow, as calculated by Equation 5, will be:

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

This gives 16.9 air changes per hr, 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. 8. 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. 9 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 1.6 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 forces of wind and temperature head that create flow through other types of openings. The capacity of a ventilator depends upon four things: (1) its location on the roof; (2) the resistance it and the ductwork offer to air flow; (3) the height of draft; and (4) the efficiency of the ventilator in utilizing the kinetic energy of the wind for inducing flow by centrifugal or ejector action.

For maximum flow induction, a ventilator should be located on that part of the roof where it will receive the full wind without interference. If ventilators are installed within the suction region created by the wind passing over

the building, or in a light court, or on a low building between two high buildings, their performance will be seriously influenced. Their normal ejector action, if any, may be completely lost.

The base of the ventilator should be of a taper-cone design to produce the effect of a bell-mouth nozzle whose coefficient of flow is considerably higher than that of a square-entrance orifice. If a grille is provided at the base, or if the base or structural members present obstructions, additional resistance is introduced, and the base opening should be increased in size accordingly.

Air inlet openings located at lower levels in the building, should be at least equal to, and preferably larger than, the combined throat areas of all roof ventilators. The air discharge by a roof ventilator depends on wind velocity and temperature difference, and, in general, its performance will be the same as any monitor opening located in the same place but, due to the four capacity factors already mentioned, no simple formula can be devised for expressing ventilator capacity.

Roof ventilators may be classified as stationary, pivoting, or oscillating, and rotating. Generally, these have a round throat, but the continuous-ridge ventilator would fall in the stationary classification. When selecting roof ventilators, some attention should be given to ruggedness of construction, storm-proofing features, dampers and damper-operating mechanisms, possibility of noise, original cost, and maintenance.

Natural ventilation units may be used to supplement power-driven supply fans, and under favorable weather conditions it may be possible to stop the power-driven units. Units are not subject to code tests for ratings. Generally, they must be selected from manufacturers' tables. It is, therefore, very important to consider the reliability of the ratings used.

Controls

Gravity ventilators may have dampers controlled by hand, thermostat, or wind velocity, in combination with a fan. The thermostat station may be located anywhere in the building, or it may be located within the ventilator itself. The purpose of wind velocity control is to obtain a definite volume of exhaust regardless of the natural forces, the fan motor being energized when the natural exhaust capacity falls below a certain minimum, and again shut off when the wind velocity rises to the point where this minimum volume can be supplied by natural forces.

Stacks

Stacks or vertical flues are really chimneys which function through the effects of the wind and temperature difference. Like the roof ventilator, the stack outlet should be located so that the wind may act upon it from any direction. With little or no wind, the chimney effect depends entirely on temperature difference to produce a removal of air from the rooms where the inlet openings are located.

GENERAL VENTILATION RULES

A few of the important considerations, in addition to those already outlined, are:

1. Buildings and ventilating equipment should not be oriented for a particular wind direction, but should be designed for effective ventilation with all wind directions, since there are only a few places on the continent where there are prevailing winds. Even if a wind direction prevailed 80 percent of the time, it would be necessary to provide safe adequate ventilation for the remaining 20 percent.
2. Inlet openings should not be obstructed by buildings, trees, sign boards, etc., outdoors, nor by partitions indoors.
3. Greatest flow per square foot of total opening is obtained by using inlet and outlet openings of nearly equal areas.
4. Direct short circuits between openings on two sides at a high level may clear the air at that level without producing any appreciable ventilation at the level of occupancy.
5. In order that temperature difference may produce a motive force, there must be vertical distance between openings. That is, if there are a number of openings available in a building, but all are at the same level, there will be no motive head produced by temperature difference, no matter how great the difference might be.
6. In order that the force of temperature difference may operate to maximum advantage, the vertical distance between inlet and outlet openings should be as great as possible. Openings in the vicinity of the neutral zone are least effective for ventilation.
7. Openings much larger than the calculated areas are sometimes desirable, especially when an increase in occupancy may occur, or when extremely hot days may be anticipated. In the former case, free openings should be located at the level of occupancy for psychological reasons.

REFERENCES

[1] Alfred Bailey and N. D. G. Vincent: Wind pressure on buildings, including effects of adjacent buildings (*Journal*, Institute of Civil Engineers, Vol. 20, No. 8, October 1943, p. 243).

[2] J. C. Rathbun: Wind forces on tall buildings (*American Society of Civil Engineers Transactions*, Paper 2056, Vol. 105, 1940, p. 1).

[3] T. C. Min: Winter infiltration through swinging-door entrances in multi-story buildings (ASHAE TRANSACTIONS, Vol. 64, 1958, p. 421).

[4] J. E. Emswiler: Neutral zone in ventilation (ASHVE TRANSACTIONS, Vol. 32, 1926, p. 59).

[5] Axel Marin: Influence of stack effect on the heat loss in tall buildings (ASHVE TRANSACTIONS, Vol. 40, 1934, p. 377).

[6] F. C. Houghten and Carl Gutberlet: ASHVE RESEARCH REPORT No. 1069—Heating requirements of an office building as influenced by the stack effect (ASHVE TRANSACTIONS, Vol. 43, 1937, p. 437).

[7] G. L. Smith: Air leakage due to stack effect in multi-story buildings (*Air Conditioning, Heating and Ventilating*, July 1958, p. 73).

[8] D. R. Bahnfleth, T. D. Moseley, and W. S. Harris: ASHAE RESEARCH REPORT No. 1614—Measurement of infiltration in two residences, Part I—Technique and measured infiltration (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 439). D. R. Bahnfleth, T. D. Moseley and W. S. Harris: ASHAE RESEARCH REPORT No. 1615—Measurement of infiltration in two residences, Part II—Comparison of variables affecting infiltration (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 453).

[9] J. E. Emswiler and W. C. Randall: Pressure differences across windows in relation to wind velocity (ASHVE TRANSACTIONS, Vol. 36, 1930, p. 83).

[10] F. C. Houghten and C. C. Shrader: ASHVE RESEARCH REPORT No. 686—Air leakage through the openings in buildings (ASHVE TRANSACTIONS, Vol. 30, 1924, p. 105). C. C. Schrader: ASHVE RESEARCH REPORT No. 704—Air leakage around window openings (ASHVE TRANSACTIONS, Vol. 30, 1924, p. 313). F. C. Houghten and M. E. O'Connell: ASHVE RESEARCH REPORT No. 803—Air leakage studies on metal windows in a modern office building (ASHVE TRANSACTIONS, Vol. 34, 1928, p. 321). F. C. Houghten and M. E. O'Connell: ASHVE RESEARCH REPORT No. 815—Air leakage through a pivoted metal window (ASHVE TRANSACTIONS, Vol. 34, 1928, p. 519). W. M. Richtmann and C. Brasi: ASHVE RESEARCH REPORT No. 817—Effect of frame calking and storm windows on infiltration around and through windows (ASHVE TRANSACTIONS, Vol. 34, 1928, p. 547). G. L. Larson, D. W. Nelson, and R. W. Kubasta; ASHVE RESEARCH REPORT No. 909—Air infiltration through double-hung wood windows (ASHVE TRANSACTIONS, Vol. 37, 1931, p. 571). J. E. Emswiler and W. C. Randall: The weathertightness of rolled section steel windows (ASHVE TRANSACTIONS, Vol. 34, 1928, p. 527). D. O. Rusk, V. H. Cherry, and L. Boelter: Air infiltration through steel framed windows (ASHVE TRANSACTIONS, Vol. 39, 1933, p. 169).

[11] *Aluminum Window Specifications 1960* (Aluminum Window Manufacturers Association, New York, N. Y.)

[12] A. P. Kratz and S. Konzo: Fuel saving resulting from the use of storm windows and doors (ASHVE TRANSACTIONS, Vol. 42, 1936, p. 87).