Table 4 .... Average Air Changes per 24 hr for Storage Rooms due to Door Openings and Infiltration[a,b] (Room Temp above 32 F)

Volume cu ft	Air Changes per 24 hr	Volume cu ft	Air Changes per 24 hr
200	44.0	6,000	6.5
300	34.5	8,000	5.5
400	29.5	10,000	4.9
500	26.0	15,000	3.9
600	23.0	20,000	3.5
800	20.0	25,000	3.0
1,000	17.5	30,000	2.7
1,500	14.0	40,000	2.3
2,000	12.0	50,000	2.0
3,000	9.5	75,000	1.6
4,000	8.2	100,000	1.4
5,000	7.2		

[a] For heavy usage, multiply the above values by 2.
[b] For long storage, multiply the above values by 0.6.

practical and effective. From Fig. 7D and 7E, it was indicated that the infiltration through a revolving door (except a small portion past the door seals) is almost unaffected by the height of the building, the difference in pressure between the indoors and outdoors, and fan operation.

From the typical examples for swinging door and revolving door, aforementioned, it may be of interest to note that the infiltration rate through a swinging door is about 900 cu ft per person for a single-bank entrance, and 550 cu ft per person for a vestibule-type entrance.

Under the same conditions, the infiltration is about 60 cu ft per person for a manually revolving door and 32 cu ft per person for a motor-driven type. In other words, the revolving door is essentially a good air lock. The infiltration rate is primarily the amount of the displacement of air produced by the revolving of the doors.

However, it has been observed during field tests of some 23 tall commercial buildings in Cleveland and Pittsburgh, and a few other buildings in New York and Chicago, that the revolving door has many drawbacks which offset the service of handling the large volume of entrance traffic provided by the swinging doors.

Cold Storage Rooms

Each time the door of a storage room is opened some air from the outside enters. This warm outside air must be reduced to the temperature of the refrigerated space thus adding to the refrigeration load. It is difficult to determine the load accurately. The traffic in a refrigerator usually varies with its size or volume and the number of door openings is dependent upon the volume rather than the number of doors. The air changes listed in Table 4 are based on experience and have proven practical.

Table 4 does not apply if additional ventilation is required. When fresh air is provided, it causes the refrigerated space to be under an air pressure slightly above atmospheric. Under these conditions, cold air will leave the refrigerated space whenever the door is opened. The ventilating load under these conditions will replace the door opening load, if greater.

Effect of Supply and Exhaust Systems

Buildings are sometimes pressurized to reduce or eliminate infiltration by providing a substantial excess of outside supply air over exhaust. The variation in pressure difference due to wind greatly complicates the application of such a system. Unless the excess air supply is automatically adjusted, the inside pressure will often be either greater or smaller than required. When the pressures on the windward side are balanced the supply air required will be about equal to the infiltration that would otherwise occur due to exfiltration on the leeward sides unless the building spaces are tightly sealed from one another. This is further complicated in tall buildings by the variations in pressure difference across the walls with height due to temperature forces. If the normal pressure differences at levels furthest from the neutral zone are to be overcome a total outside air supply much in excess of the infiltration that would otherwise occur must be provided unless the various floors are isolated from one another. In tall buildings at least, pressurizing to the extent required to overcome infiltration will result in a substantial increase in heating or cooling loads except for those buildings with very tight enclosures.

Where mechanical ventilating systems are designed to produce positive or negative pressures in an enclosure, if the specified rate at which air is to be supplied or removed exceeds the calculated infiltration rate, it is common practice to use the greater value in calculating heating or cooling requirements.

Infiltration and Air for Combustion

Infiltration in buildings normally supplies the air required for combustion by fuel-burning appliances, but in some cases weatherstripping, sealing, and calking may reduce infiltration to the point that special openings must be provided to supply adequate air to the heating appliances. This need for combustion air is recognized in various building codes. For instance, the State Building Construction Code of New York State for One- and Two-Family Dwellings[18] requires that an air inlet area not less than the area of the smoke pipe connection be provided if adequate air supply at all times is not assured. Similarly, the same code for multiple dwellings requires a permanent opening to the outdoor air for rooms containing fuel-burning appliances having a gross capacity in excess of 250,000 Btuh.

NATURAL VENTILATION

Ventilation by natural forces finds application in industrial plants, public buildings, schools, dwellings, garages, and in farm buildings.

The natural forces available for moving air into, through, and out of buildings are: (*a*) wind forces, and (*b*) the difference in temperature between the air inside and outside a building. The air movement may be caused by either of these forces acting alone, or by a combination of the two, depending upon atmospheric conditions, building design, and location. The ventilating results obtained will vary, from time to time, due to variation in the velocity and direction of the wind, and the temperature difference. The arrangement, location, and control of the ventilating openings should be such that the two forces act cooperatively rather than in opposition.

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 4.

$$Q = \frac{H}{c_p \times \rho \times 60(t_i - t_o)} = \frac{H}{1.08(t_i - t_o)} \quad (4)$$

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.

Flow due to Wind

In considering the use of natural wind forces for producing ventilation, account must be taken of: (1) average wind velocity; (2) prevailing wind direction; (3) seasonal and daily variations in velocity and direction; and (4) local wind interference by nearby buildings, hills, or other obstructions of similar nature.

Values are given in Table 1, Chapter 27, for the average wind velocities for the months June to September in various localities throughout the United States, while Table 1, Chapter 26, lists similar values for the winter. In almost all localities, the summer wind velocities are lower than those in the winter, and in about two-thirds of the localities the prevailing direction is different during the summer and winter. While the tables give no average velocities below 5 mph, there will be times when the velocity is lower, even in localities where the seasonal average is considerably above 5 mph. There are relatively few places where the velocity falls below one-half of the average for many hours per month. Consequently, if the natural ventilating system is designed for wind velocities of one-half of the average seasonal velocity, it should prove satisfactory in almost every case.

Equation 5 may be used for calculating the quantity of air forced through ventilation openings by the wind, or for determining the proper size of such openings to produce given results:

$$Q = EAV \quad (5)$$

where

Q = air flow, cubic feet per minute.
A = free area of inlet openings, square feet.
V = wind velocity, feet per minute, = miles per hour × 88.
E = effectiveness of openings. (E should be taken at 0.50 to 0.60 for perpendicular winds, and 0.25 to 0.35 for diagonal winds.)[19]

The precision of results obtained by the use of Equation 5 depends upon the placing of the openings, as the formula assumes that ventilating openings have a flow coefficient 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.
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.

Flow Due to Temperature Differences

The flow due to stack effect can be calculated from Equation 6, which is based on the flow equation for a sharp edged orifice, and Equation 2, assuming the indoor and outdoor temperatures are close to 80 F.

$$Q = 9.4A\sqrt{h(t_i - t_o)} \quad (6)$$

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.

Equation 6, is applicable only if there is no significant resistance to flow within the building from inlets to outlets.

The importance of maintaining the greatest possible height between inlets and outlets is obvious.

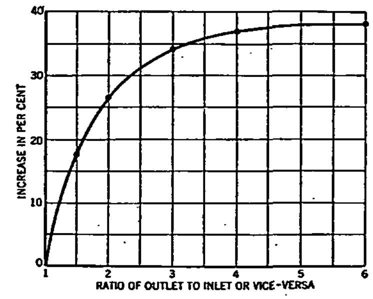

Fig. 8 .... Increase in Flow Caused by Excess of One Opening Over Another

Effect of Unequal Openings

The largest flow per unit area of openings is obtained when inlets and outlets are equal, and Equations 5 and 6 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. 8.

Flow Due to Combined Wind and Stack Effect

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 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 independ-