Table 3 . . . . Infiltration Through 72-Inch Revolving Door and 36-Inch Swinging Door[a, b]

(Cubic feet per person per passage)

Usage	Freely-Revolving Door	Door Equipped with Brake
Infrequent	75	60
Average	60	50
Heavy	40	40
36-Inch Swinging Door	20 to 100	

[a] These figures are based on the assumption that there is no wind pressure and that swinging doors are in use in one wall only. Any swinging doors in other walls should be kept closed to insure air conditioning in accordance with these recommended standards.

[b] From *Application Engineering Standards for Air Conditioning for Comfort* 1947, Air Conditioning & Refrigeration Institute Inc., Washington, D. C. and from experimental data of National Bureau of Standards. Used by permission.

system tended to raise or lower the inside pressure by blower action. The frequency of door usage would also affect the amount of leakage per passage.

Air Change Method

The amount of air leakage may be estimated by assuming a certain number of air changes per hour for each room, the number of changes assumed being dependent upon the type, use, and location of the room, as indicated in Table 4. Where it is not possible to determine or predetermine with accuracy the width of crack or clearance of windows, or when other sources of air leakage cannot readily be evaluated, as is often the case, the use of the air change method may be justified.[8]

The values in Table 4 may be used with reasonable accuracy for residences, and are the requirements for each room. The total infiltration allowance for the entire building should be one-half the sum of the infiltration allowances of the individual rooms, since whatever air enters on the windward side, generally leaves the building on the leeward side, and the infiltration requirements therefore do not exist simultaneously on all sides or in all rooms. An allowance of one air change per hour for all sources of air leakage for the entire volume may be considered average for a well constructed residence.

The air leakage, due to opening and closing of doors in vestibules, is sometimes based on the air change method, even though the air leakage estimates for other rooms are based on the crack method. Except for vestibules and reception halls, it is not advisable to attempt to apply the air change method to factories and industrial and commercial buildings, because of the wide variations in the type and percentage of fenestration which is the principal source of air leakage in such buildings.

INFILTRATION DUE TO TEMPERATURE DIFFERENCE

The air exchange due to temperature difference, indoor to outdoor, is a chimney effect, causing air to enter through openings at lower levels, and to leave at higher levels[9] when the building is heated or causing flow in the reverse direction when the building is cooled. This air exchange is usually of considerable importance in tall, single-story buildings with openings near the ground level and near the ceiling; it should also be considered in tall, multi-story buildings unless the sealing between various floors is nearly perfect; and may be appreciable in one-story buildings with basements and attics.

The flow of air through a building under the influence of indoor-outdoor temperature difference is quite complex except for single-story structures without a basement or attic. It can best be understood by visualizing the building as a complex chimney with a number of passages and a number of restrictions. The basement represents the lower section of this imaginary chimney with air moving inward through cracks in the walls and around windows and doors. The air then moves upward through cracks and openings in the floor which acts like a damper in the chimney. Above the floor the chimney has many parallel passages consisting of the several rooms and the hollow wall spaces in certain types of construction. These separate passages are all interconnected by cracks and also communicate with the outdoors through cracks and fissures. The ceiling acts as another damper with air flowing upward through various cracks and openings. This condition is repeated in every story of a multi-story building and can be further complicated by open stairways, elevator shafts, and utility ducts. The attic finally represents the union of all the parallel passages in the chimney with the outward flow of air being again restricted by the roof construction.

Since the chimney effect in a building produces a negative pressure and an inward flow of air at the lower levels and positive pressure and outward flow at the higher levels, a neutral zone[10] exists near midheight where there is no pressure difference between indoors and outdoors, if the openings are about uniformly distributed in a vertical direction. At the neutral zone there would be no air flow through openings in the outside walls as a result of temperature differences.

The infiltration caused by the indoor-outdoor temperature differences can be calculated by means of the crack method described earlier in this chapter for determining the infiltration caused by wind pressure. This is done by determining the equivalent wind velocity that would produce the same rate of infiltration as was caused by the prevailing temperature difference. It is recommended that one-half the total crack length of the building be used for this computation. To determine the infiltration caused by the temperature difference, one-half the crack length of the building is multiplied by the infiltration coefficient from Table 2 corresponding to the equivalent wind velocity computed from the following equation developed from basic relationships between velocity, pressure, density, and temperature.

Table 4 . . . . Air Changes Taking Place under Average Conditions in Residences, Exclusive of Air Provided for Ventilation[a]

Kind of Room or Building	Number of Air Changes Taking Place per Hour
Rooms, 1 side exposed	1
Rooms, 2 sides exposed	1½
Rooms, 3 sides exposed	2
Rooms, 4 sides exposed	2
Rooms with no windows or outside doors	½ to ¾
Entrance Halls	2 to 3
Reception Halls	2
Bath Rooms	2

[a] For rooms with weatherstripped windows or storm sash, use ½ these values, where applicable, but never less than ½ air change.

$$V_e = B\sqrt{h(t_i - t_o)} \quad (1)$$

where

V_e = equivalent wind velocity corresponding to the temperature difference $(t_i - t_o)$, miles per hour.
h = height of rooms, feet.
t_i = indoor temperature, Fahrenheit.
t_o = outdoor temperature, Fahrenheit.
B = a constant to account for leakage through floor and ceiling and for the number of stories in the building.

The constant B would be 0.12 for a single-story building or for any story of a multi-story building whose floor and ceiling were impervious to air, whereas the value of B has been found to be approximately unity for a single-story frame building with basement and attic having double wood flooring, plastered ceiling, and the walls finished with plasterboard on the inside. The value of this constant would increase as the number of stories increases and for stories farther removed from the neutral zone in either direction in buildings that lack perfect sealing between stories.

Sealing of Vertical Openings

In tall, multi-story buildings, every effort should be made to seal off vertical openings, such as stair-wells and elevator shafts, from the remainder of the building. Stair-wells should be equipped with self-closing doors, and, in exceptionally high buildings, should be closed off into sections of not over 10 floors each. Plaster cracks should be filled. Elevator enclosures should be tight, and solid doors should be used.

If the sealing of the vertical openings is made effective, no allowance need be made for the chimney effect. Instead, the greater wind movement at the greater heights makes it advisable to install additional heating surface on the upper floors above the level of neighboring buildings, this additional surface being increased as the height is increased. One arbitrary rule is to increase the heating surface on floors above neighboring buildings by an amount ranging from 5 percent to 20 percent. This extra heating surface is required only on the windward side and on windy days, and hence, automatic temperature control is especially desirable with such installations.

In stair-wells that are open through many floor levels, although closed off from the remainder of each floor by doors and partitions, the stratification of air makes it advisable to increase the amount of heating surface at the lower levels, and to decrease the amount at higher levels. One rule is to calculate the heating surface of the entire stair-well in the usual way, and to place 50 percent of this in the bottom third, the normal amount in the middle third, and the balance in the top third.

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[11] 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.

WIND FORCES

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 2, Chapter 13, for the average wind velocities for the months June to September in various localities throughout the United States, while Table 1, Chapter 12, 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 3 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:

$$Q = EAV \quad (3)$$

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.)[12]

The precision of results obtained by the use of Equation 3, depends upon the placing of the openings, as the formula assumes that ventilating openings have a flow coefficient