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The Principles of Natural Ventilation of Buildings

Enquiries received at the Building Research Station show that there is a demand for notes summarizing available information on selected building topics. To meet this need the Building Research Station Digests are issued as a monthly series, numbered consecutively.

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Garston, Watford, Herts.

This *Digest* is concerned with natural ventilation, the process by which the air in a building or part of a building is removed and replaced by air from outside by the action of natural forces as distinct from ventilation effected by the aid of mechanical equipment such as fans. It outlines the principles involved and indicates the methods by which the rate of ventilation can be assessed.

Principles

Natural ventilation depends for its operation on two motive forces, namely (*a*) wind and (*b*) stack effect. These two forces can act independently, in conjunction with, or in opposition to, each other. Wind is not controllable and only limited control of stack effect is possible, for in part it depends on the external air temperature. Suitable apertures must be provided in the structures to allow the air change to take place. The size, position and design of these apertures will play a part in the ventilation rate resulting from the two motive forces, insofar as these apertures allow the air to pass through them freely or offer resistance to its passage. They thus provide a means for controlling the amount of ventilation.

(*a*) Wind

The part played by the wind in ventilating a building depends in part on the fact that wind creates a difference of pressure between the air inside and that outside the building thereby encouraging air flow from the area of higher pressure to that of lower pressure. On the windward side of the building the outside pressure will normally be higher than the inside pressure. This pressure difference results in the movement of air from the outside through any apertures to the inside. Conversely on the leeward side of the building the pressure outside will be less than that inside and the inside air will thus tend to pass through any apertures to the outside. It may be said, therefore, that a positive pressure exists on the windward side and a negative pressure on the leeward side of the building. The rate at which the air change occurs will, therefore, in part be governed by the pressure difference between the air inside and that outside the building; the greater the wind speed, the greater the pressure difference and therefore the greater the rate of air change. (See Figs. 1, 5A, 5B and 6.)

(*b*) Stack Effect

Air change in a building due to " stack effect " is caused by the difference in temperature that usually exists between the air inside and that outside the building.

If the air temperature inside is higher than that outside a building the warmer air tends to rise and pass through any apertures which exist in the upper part of the building and to be replaced by colder air from outside entering through apertures in a lower part of the building. The rate at which such air change will occur depends on the temperature difference between the inside and outside air, on the height between the inlet and the outlet, and the size and design of the apertures. This process can be utilised in designing a natural ventilation scheme, a typical example being the provision of ventilator n the ridge of a roof to serve as outlets, with various apertures provided at a low level in the building to serve as inlets. Another example of stack effect is the air movement resulting from a heated flue; here the temperature in the flue is much greater than that of the air outside the building, and the air movement is correspondingly rapid. (See Figs. 2A, 2B and 4.)

Insofar as the pressure at the outlet or inlet of such a ventilation system can be affected by wind, the extent to which the stack effect operates will be governed partly by the wind pressure and partly by the design of the apertures.

Apart from the apertures in the structure it has been shown above how natural ventilation is dependent on wind speed and temperature, both of which vary considerably. It follows, therefore, that although natural ventilation can be quite satisfactory for many purposes the rate will vary from hour to hour and if this is unacceptable a mechanical system must be used. Some degree of control is obtainable by suitable design of the natural system, e.g. by using a constant flow type of ventilator. Otherwise reliance must be placed on adjustable openings.

Design and Calculations for a Natural Ventilation System

The apertures for natural ventilation, particularly in domestic buildings, are often provided in a rather haphazard or rule of thumb manner. In dwellings it is based almost entirely on the local byelaws which require, for example, in all habitable rooms, either the provision of an air vent or a flue of certain cross sectional area. The occupants of dwellings, however, have a large measure of control over the ventilation due to the comparatively large area of openable windows and doors, the byelaw requirements being aimed at providing at least some ventilation in all habitable rooms when all the windows and doors are closed. In other buildings, such as factories or assembly buildings, where either the factory process or the presence of a large number of people necessitate a certain ventilation rate, the individual occupants have not the same ease of control of any openable windows which may exist and it is particularly desirable in these cases that some reasonable basis should be adopted for the design of the natural ventilation system. Such a design must first take into account the direction and speed of prevailing winds and the normal range of external and internal temperatures. It is obvious that it will be impossible to obtain a constant natural ventilation rate, and any calculations must therefore be based on certain assumptions of the external conditions. These are the speed and direction of the wind and the external air temperature.

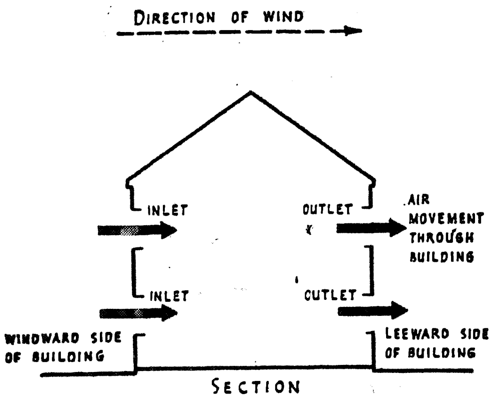


FIG. 1.—Air movement through building due to wind only.

FIG. 2 A.

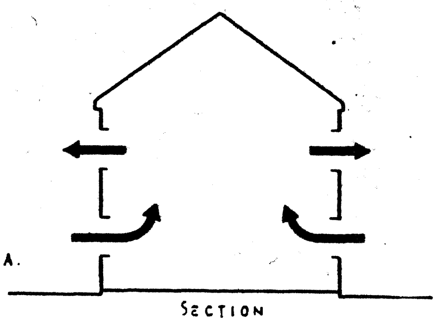
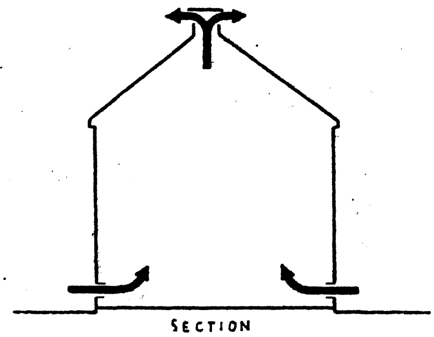


FIG. 2 B.



Air movement through building due to stack effect with no wind, when inside temperature is higher than outside temperature.

The average speed of the wind on an exposed site is often taken as 10 m.p.h.; where there is considerable sheltering effect such as may occur in a built-up area it is normally assumed to be only 3 m.p.h. A typical average winter air temperature for the normal working period during the day is 45°F. It must be realised, however, that the use of the average values as design figures imply that the ventilation will be less than the assumed value for a considerable part of the time. Normally the direction should be taken as that of the prevailing wind, but there may be local conditions due to adjacent buildings or high trees that may necessitate a decision on the site as to the direction to be assumed for design.

At times of high wind speed it is likely that the air change in a building due to the action of the wind will predominate and swamp the air change due to stack effect. At other times, when comparatively still conditions exist, the stack effect may provide the major contribution.

These changing conditions should, therefore, be taken into account in any scheme for natural ventilation and the openings arranged to utilize both wind and stack effects if necessary.

The air change rates obtained by natural ventilation are influenced by many factors such as the variability of the speed and direction of the wind, temperature changes, the interplay of wind and stack effects, the varying shapes of buildings, and the existence of obstructions to the flow of air through the building such as floors and partitions.

The following methods may be used for simple cases, such as assembly halls and open single storey factories to give an indication of the likely air change rates due to wind and stack effect. They should not be used where the building is of complex shape or where the air flow may be obstructed by internal partitions. Under these conditions the pressures created at any particular inlet or outlet may vary as a result of the complex air flow pattern which may occur in and around the building. It is first necessary :—

(*a*) to assume the speed and direction of the wind on the basis already mentioned, and

(*b*) to decide which openings will act as inlets and which as outlets, firstly under the action of the wind and secondly with stack effect.

The calculation may then be made as follows.

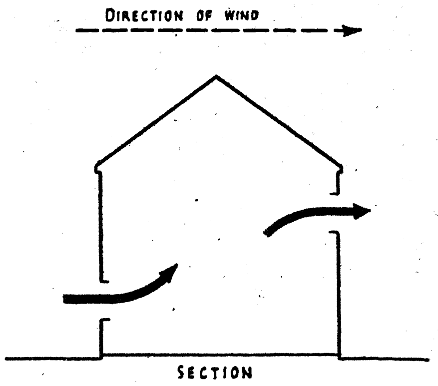


FIG. 3.—Air movement through building due to wind and stack effect.

(i) Calculation of the Ventilation Rate Due to Wind

The following expression will give the approximate rate at which air change will occur in a building, rectangular on plan, when the direction of the wind is normal to, i.e. at right angles to, one of the sides of the building, and the areas of inlets and outlets are *equal* :—

$$\left.\begin{array}{l}\text{The rate of air}\\ \text{flow in cubic}\\ \text{feet per hour}\\ \text{through the}\\ \text{building}\end{array}\right\} = 3150 \times \left\{\begin{array}{c}\text{area of}\\ \text{inlets}\\ \text{in}\\ \text{sq. ft.}\end{array}\right\} \times \begin{array}{l}\text{wind speed}\\ \text{in miles per}\\ \text{hour}\end{array}$$

In this simple case, for any assumed wind speed, either the approximate rate of air flow with a known area of inlets can be obtained or alternatively the area of inlet necessary to provide a desired rate of air flow can be estimated.

If the direction of the wind is not at right angles to the face of the building then some correction to the above expression is necessary : for example, if it is at an angle of 45° to an elevation of the building then it is usual to assume that the rate of air flow will be reduced to 50 per cent. of the value given by the above expression calculated for the appropriate area of inlet and outlet.

If in either of the above cases the area of outlets is appreciably different from the area of inlets, then an adjustment to the above expression is necessary to take this difference into account. This adjustment will consist of substituting another value for the figure 3150 in accordance with the following Table, in which the values in the first column are the ratios of the total outlet area to the total inlet area :—

$\dfrac{\text{Area of outlets}}{\text{Area of inlets}}$	Value to be substituted for 3150 in above expression
1	3150
2	4000
3	4250
4	4350
5	4400
3/4	2700
1/2	2000
1/4	1100

From this Table it will be seen that if the area of outlets is twice the area of the inlets then the expression reads :—

$$\left.\begin{array}{l}\text{Rate of air}\\ \text{flow in cu.}\\ \text{ft./hour}\end{array}\right\} = 4000 \times \text{area of inlets} \times \text{wind speed}$$

(ii) Calculation of the Ventilation Rate Due to Stack Effect

The approximate rate at which air change will occur in a building due to the temperature of the air inside being different from that outside the building and where the area of inlets is

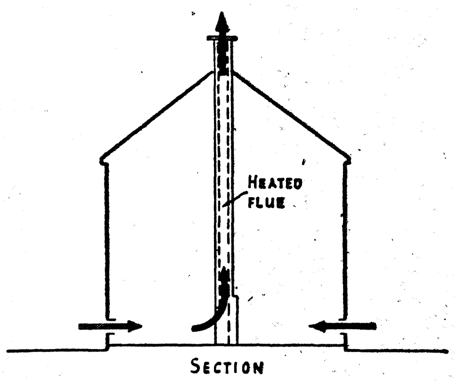


FIG. 4.—Air movement through building due to stack effect of flue.

equal to the area of outlets is given by the following expression :—

$$\left.\begin{array}{l}\text{The rate of air flow}\\ \text{in cu.ft. per hour}\end{array}\right\} = \left\{\begin{array}{l}540 \times \text{area of}\\ \text{inlets in sq. ft.}\end{array}\right\} \times \sqrt{\left.\begin{array}{l}\text{height in ft. be-}\\ \text{tween inlets and}\\ \text{outlets}\end{array}\right\} \times \left\{\begin{array}{l}\text{temperature difference}\\ \text{between inside and out-}\\ \text{side air in degrees F.}\end{array}\right.}$$

This expression will require adjustment in accordance with the following Table where the area of outlets is appreciably different from the area of inlets :—

$\dfrac{\text{Area of outlets}}{\text{Area of inlets}}$	Value to be substituted for 540 in above expression
1	540
2	680
3	720
4	740
5	745
3/4	455
1/2	340
1/4	185

Example

It is desired to assess the ventilation that will occur in a building with an internal air temperature of 65°F. and an external air temperature of 45°F. The building is rectangular on plan with openings equal to 10 sq. ft. on each of the long sides and 5 sq. ft. on each end : half the openings on each side and end are at a high level and the other half are at a low level, the distance between the centres of the high and low level openings being 20 ft. The prevailing wind is at right angles to one of the long sides :—

Air flow due to wind

$$\frac{\text{Area of outlets}}{\text{Area of inlets}} = \frac{20}{10} = 2$$

$$\left.\begin{array}{l}\text{Rate of air}\\ \text{flow (cu.ft.}\\ \text{per hour)}\end{array}\right\} = 4000 \times 10 \times \text{wind speed (m.p.h.)}$$

$$\left.\begin{array}{l}\text{Thus for exposed site air}\\ \text{flow (assuming a wind}\\ \text{speed of 10 m.p.h.)}\end{array}\right\} = 400{,}000 \text{ cu.ft. per hour}$$

$$\left.\begin{array}{l}\text{and for built-up area air}\\ \text{flow (assuming effective}\\ \text{wind speed of 3 m.p.h.)}\end{array}\right\} = 120{,}000 \text{ cu.ft. per hour}$$

Air flow due to stack effect :—

$$\frac{\text{Area of outlets}}{\text{Area of inlets}} = \frac{15}{15} = 1$$

$$\left.\begin{array}{l}\text{Rate of air flow}\\ \text{(cu.ft. per hour)}\end{array}\right\} = 540 \times 15 \text{ sq. ft.} \times \sqrt{20 \text{ ft.} \times 20°\text{F.}}$$

$$= 160{,}000 \text{ cu.ft. per hour}$$

In practice the pressures created by wind and by the temperature difference between the inside and the outside will act at the same time and the estimated air flow should strictly be made by combining these acting pressures. It may be shown however that, considering the variability of the processes, the error involved in taking the larger of the estimates based either on wind or stack effect separately is generally small. In this example, therefore, the air change rate for an exposed site may be assumed to be approximately 400,000 cubic feet per hour, this air change being due to the action of wind : if the building is on a sheltered site, such as may occur in a built-up area, the air change rate may be assumed to be approximately 160,000 cubic feet per hour, this being due to stack effect.

Ventilation is often expressed as a number of air changes per hour and this is of course obtained by dividing the air change rate of the building in cubic feet per hour by the volume of the building in cubic feet.

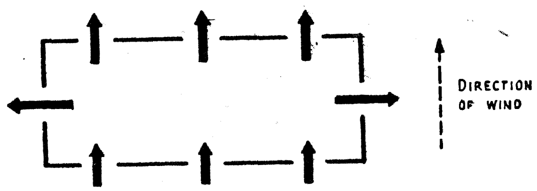


FIG. 5A.—Air movement through building due to wind normal to building front, showing inlets and outlets.

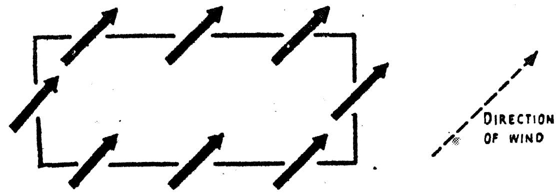


FIG. 5B.—Air movement through building due to wind at angle of 45° to building front, showing inlets and outlets.

(iii) Calculation of Rate of Heat Loss

During the heating season replacement of air within a heated building by colder air from outside may place an appreciable load on the heating system and this has to be taken into account in designing the heating system. The rate of heat loss for a given rate of air exchange can be calculated from the following equation :

$$\left.\begin{array}{l}\text{Rate of heat loss}\\ \text{(B.Th.U. per hour)}\end{array}\right\} = \begin{array}{c}0.019 \times \text{Rate of air flow}\\ \text{(cubic feet per hour)}\\ \text{Temperature difference (°F.)}\end{array} \times$$

where 0.019 is the amount of heat in B.Th.Us. required to raise the temperature of 1 cubic foot of air through 1°F.

Thus in the above example the rate of heat loss on an exposed site when the rate of air flow is 400,000 cubic feet per hour and the temperature difference is 20°F. will be 150,000 B.Th.U. per hour; on the sheltered site with an air flow of 160,000 cubic feet per hour the corresponding rate of heat loss will be 61,000 B.Th.U. per hour.

Effect of Building Plan

In practice the process of air change in many buildings is more complicated than that dealt with in the example. For instance, the presence of floors and internal partitions may restrict the passage of air, a more complex building shape may complicate the pressure distribution around the building, or heated flues may create their own stack effect. Calculations to allow for such features, although involved, could be made in some cases, but where there is considerable complication of the above type, recourse is usually made to measurements obtained in buildings of similar types.

A particular type of building in which it is difficult to calculate the air change rate accurately is the dwelling house. It has been found by measurements that the typical air change rate of small modern houses when heated in winter with doors and windows shut ranges from one to two per hour, and that this rate is, on the average, increased due to the opening of windows and doors by the occupants, by about one air change per hour. Measurements have also been made in houses by various investigators of the rate at which air is drawn up a heated flue. A typical figure for an open fire with the normal throat is 6,000 cubic feet of air per hour which may increase the overall rate by as much as half an air change per hour; if the throat of the open fire does not exceed 20 sq. in.

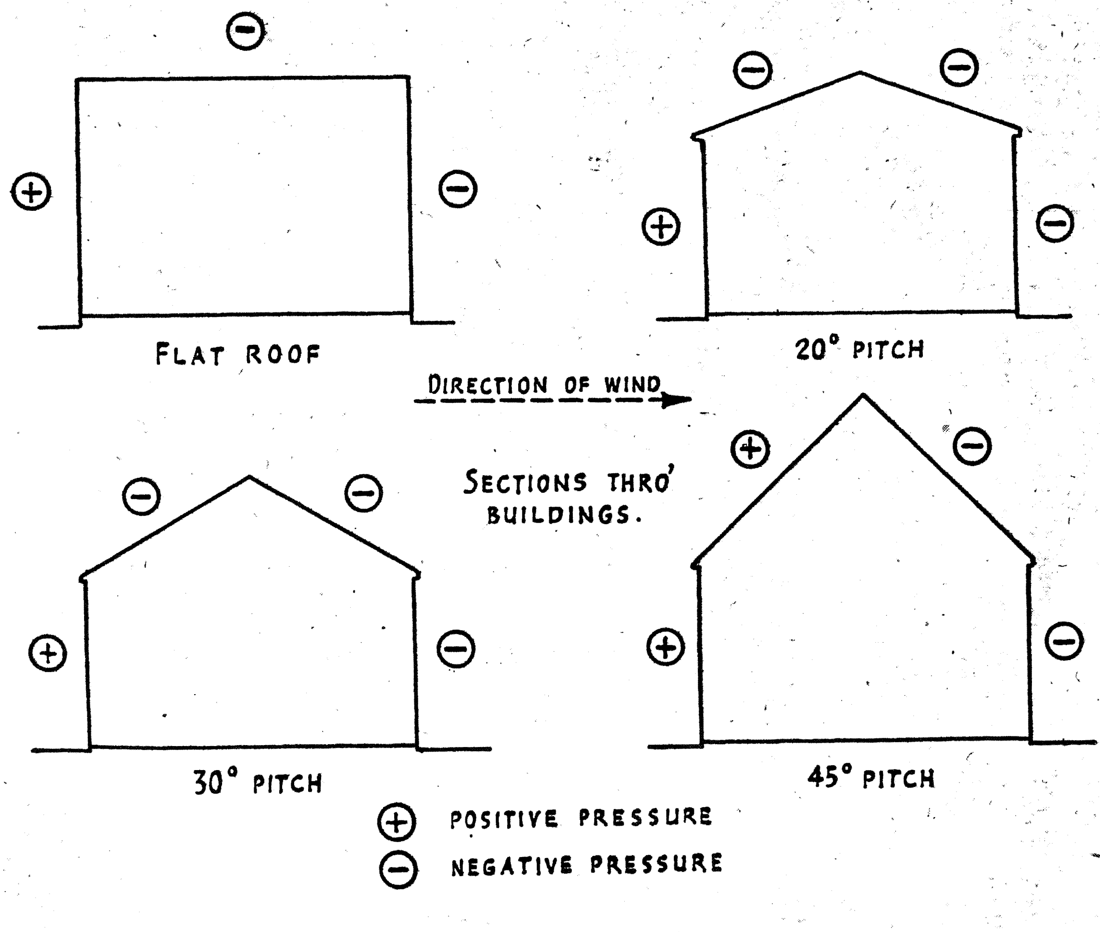


FIG. 6.—Diagram showing areas of positive and negative pressures produced by wind normal to the building front: openings on faces of positive pressure will serve as inlets and those on faces of negative pressure, as outlets, for air movement due to wind.

in area, or if the applicance is either a closed stove or a flued gas heater, the rate of air flow may be even less than half this figure.

Standards of Ventilation

The Code of Functional Requirements of Buildings, Chapter 1(*c*) on "Ventilation" recommends the minimum rates of fresh air supply to buildings for human habitation, including Assembly Halls, Canteens, Factories and Workshops, Hospitals, Houses and Flats, Large Kitchens, Office Buildings, Places of Entertainment, Restaurants, Schools and Shops; in addition, the Factories Act, 1937, and subsequent regulations govern the conditions to be provided in factories.

At such times when the temperature inside a building is higher than that outside, ventilation will result in heat loss from the building, and during the heating season this ventilation heat loss will generally form part of the load on the heating installation; from considerations of fuel economy therefore excessive ventilation is undesirable. It is of interest to note that during the heating season, the heat lost by ventilation in an average small house is provided by the heating installation at a cost of approximately five shillings per week. The use of weather-stripping on the external doors of houses is a useful means of reducing, when desirable, the rate of air flow through the gaps between the doors and the frames; and, as has been indicated above, the use of a closeable stove or appliance with a restricted throat will markedly reduce the excessive rate of air flow which can occur with an open fire.

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