Natural ventilation of large hospital buildings

by P. J. JACKMAN and I. N. POTTER

Wind-tunnel tests of hospital scale models and a computer program to calculate internal air-flows were used to produce a prediction technique to determine the rates of natural ventilation of large hospitals. The technique was applied to a Harness hospital design and this article reports that the ventilation generated by wind forces in, for instance, ward areas would not be consistently adequate for the comfort and well-being of the occupants.

In the past, the supply of fresh air to hospital ward areas has normally been provided by natural ventilation. Recent trends in large hospital design have, however, given rise to some concern over the effectiveness of natural ventilation in producing continually adequate air-flow rates for the comfort of the occupants.

In particular, the 'deep-plan' type of layout leads to ventilation problems. The incorporation of courtyards into such designs was thought to promote natural ventilation as well as provide increased use of daylight through the additional exterior surfaces.

Such a design concept is embodied in the Harness hospital schemes proposed by the UK Department of Health & Social Security. The Harness designs are large complexes up to four storeys high, which, in plan, basically consist of 15 m square structural modules interspersed with 15 m square courtyards (Fig. 1).

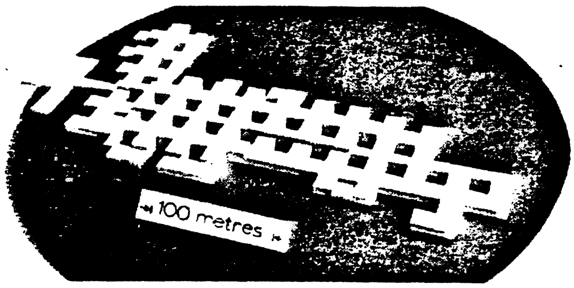

Fig. 1 Model of a typical Harness hospital

The natural flow of air into a particular building is dependent on the influences of wind and temperature differences. For large irregularly shaped buildings these influences are difficult to predict, and the calculation of the ventilation rates in all the internal areas is a complex procedure.

Natural forces

The two motive forces primarily responsible for natural ventilation are generated by the effects of temperature differences and wind impingement.

The difference in temperature, and hence in density, between the air inside a building and that outside causes a movement of air vertically through the building via openings such as lift shafts and stairwells. This temperature motivated transfer of air is called the 'stack effect'. The direction of air transfer will depend on whether the outside temperature is less or greater than the inside air temperature. If, for instance, the air temperature within the building is higher than that outside, a pressure lower than that outside is produced in the lower part of the building with an inward and upward flow of air as a consequence. Air flows outward from the upper levels of the building (Fig.2). The reverse occurs when the indoor air temperature is lower than that outdoors.

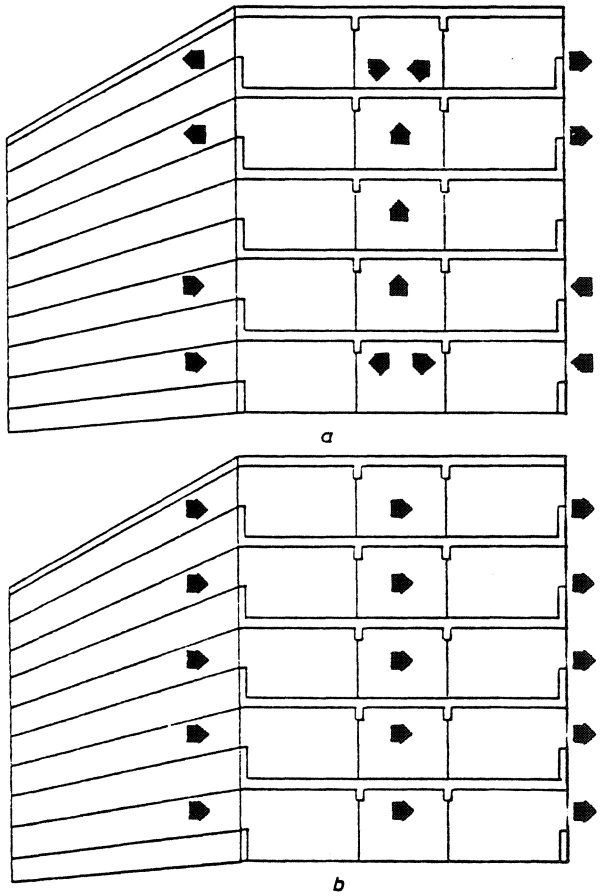

Fig. 2 a Effect of temperature differences
b Effect of wind

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The differences in pressure within a building resulting from stack effect may be calculated from a knowledge of the temperature difference and the vertical distances between openings in the facade of the building.

The Harness hospitals under consideration were either three or four storeys high with a floor-to-floor height of 3·8 m. In such buildings, the maximum pressure difference at an indoor-to-outdoor temperature differential of 20 deg C would be about 13·5 Pa. This pressure difference is equivalent to the effect of a light wind, but because of the restriction of air flow from the rooms of one floor to the next, the wind effect, which produces a basically horizontal flow of air across a building, is normally the most predominant.

The effect of wind impinging on a building is to produce a positive pressure on the windward side(s) and a negative pressure on all other sides, including the roof. The pressure differences so generated give rise to movement of air through openings or cracks on the windward face(s), across the building and out through the other faces.

The characteristics of wind vary with time and location. For instance, the prevailing wind direction differs from place to place as does the frequency of various wind speeds. The effect of local terrain on the wind pattern is also significant. The range of local wind speeds is likely to be much higher in a countryside location than in a suburban area and still higher than in a city centre. In some instances, neighbouring tall buildings or other local prominent features in the landscape modify the wind pattern still further. These many variables make the prediction of the wind effect much more difficult than temperature effects.

The situation is further complicated by the variation of surface pressures generated by the wind depending on the orientation, external shape and dimensions of the building itself. For buildings of the complexity of the Harness design, it was necessary to determine the wind pressure distribution around the outside of the buildings experimentally by using wind-tunnel testing techniques.

Wind tunnel testing

In a wind tunnel it is possible to simulate the natural wind either by modelling the local terrain over which the air passes or by installing screens which produce a similar effect (Fig. 3). Scale models of the particular Harness hospital complexes were constructed and installed in the wind tunnel (Fig. 3). The models incorporated 500 or more tiny pressure tubes terminated at the building surfaces. These pressure tubes were connected to a manometer system, so that the individual pressures could be measured.

Fig. 3 Dudley Harness hospital model in a wind tunnel

The wind-tunnel tests were conducted with the models set in a series of 12 angular positions at 30° intervals to study the effect of variations of wind direction.

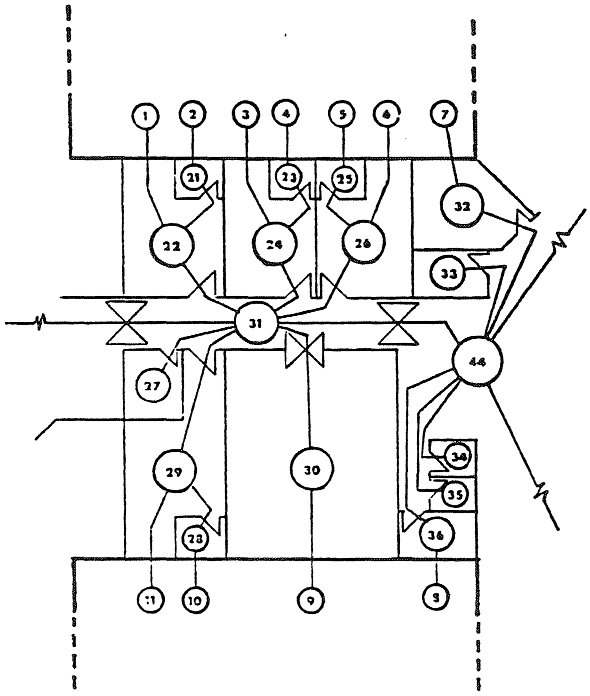

Fig. 4 Air-flow network

Internal airflow network

The pressure distribution on a building is an important factor in assessing ventilation rates, but there are other parameters which need to be taken into account. The rate at which air flows into and through a building under the influence of wind is governed by the 'leakiness' of the structure itself. Air finds its way in through open windows, external doors, specially provided apertures, if any, and through adventitious cracks between cladding components. Within the building, the air-flow paths consist of rooms and corridors, which may not be separated by internal doors. The rate that air passes through this complex network of flow paths depends on the resistance of the individual components and their relationship to one another (Fig. 4).

The components through which the air passes are normally doors and open windows (which leak even when they are closed). Available experimental data on the air-leakage characteristic of standard windows and doors were used in the calculations described below.

Computer program

The number and complexity of the air-flow paths, particularly in a large hospital building, necessitate the use of computer techniques to calculate the ventilation rates. A computer program, entitled CRKFLO and developed by BSRIA, was used in this study to calculate the air-flow rates, directions of flow and corresponding internal pressures that would be generated by the wind-pressure distributions derived in the wind-tunnel studies. Additionally, the program allowed the effect of the mechanical ventilation on toilets, bathrooms and other specific areas to be incorporated. A block diagram illustrating the input requirements of the program and the resulting outputs is shown in Fig. 5.

The natural ventilation of the wards was of particular interest and Fig. 8 shows the results calculated for a transverse wind direction with all the internal doors closed and all windows open by 12·5 mm. This setting of windows and doors was chosen to represent the situation in winter.

Fig. 8 clearly shows the effect of that mechanical ventilation of the service areas which, at zero wind speed, produced a ventilation rate between 0·5–1 air change in 70% of the ward areas and less than half an air change per hour in all but a fraction of the remaining ward areas. At the higher wind speeds, the influence of the mechanical ventilation decreased, and greater rates of ventilation were produced over a large proportion of the ward areas. However, even at a wind speed of 7 m/s only 30% of the ward areas were ventilated above a rate of 2 air changes/h and less than 10% above 3 air changes/h. The calculated ventilation rates (air changes/h) and the directions of air flow for the naturally ventilated areas of the zone are included in Fig. 7 for the wind speed and direction indicated.

To examine the effect of size and location of the wards, the single-bed and 6-bed wards will be considered separately. In relation to the wind direction shown in Fig. 7, some of the single-bed wards are located in each of the following positions:

- with windows on a leeward face within a courtyard
- with windows on a face parallel to the wind direction and within a courtyard
- with windows on a windward face
- with windows on an external face parallel to the wind direction.

For each of these positions, the variation of ventilation rate with wind speed is plotted in Fig. 9. At zero wind speed, a ventilation rate of about 0·8 air changes was produced in all the single-bed wards. This was the result of the mechanical ventilation in the service areas and, because there was a higher extract ventilation rate than supply, air was entering each ward from outside (infiltration).

In the wards which face the courtyards, the infiltration rate decreased as the wind speed was increased. This was the result of the pressure differences generated by

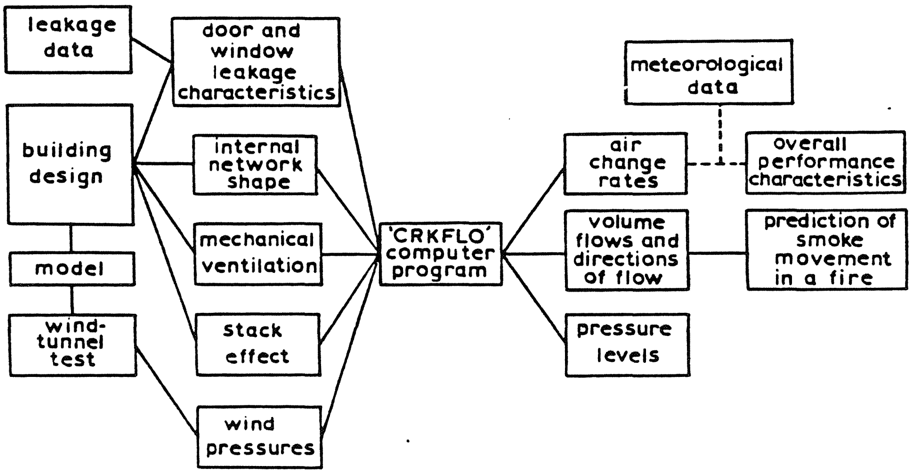

Fig. 5 Ventilation rate calculation process

Natural ventilation performance

The CRKFLO program was used to study the ventilation in several hospital designs under a wide range of conditions. For the purposes of this paper, however, the discussion of the results will be centred on one hospital design and on one typical zone within that hospital. The conclusions drawn are, nevertheless, representative of the overall findings. The layout of the selected hospital is shown in Fig. 6 on which the location in plan of the particular zone is also indicated.

The zone comprised a 1st-floor 124-bed ward area (Fig. 7). In it are three open-plan 16-bed wards, one 8-bed ward, four 6-bed wards, four 4-bed wards, two 2-bed wards and 24 single-bed wards. The diamond shape in the centre of the cruciform sections denote service areas and nurse stations, which were provided with mechanical ventilation. The bathrooms and some of the toilets (those with no external walls) were equipped with extract ventilation systems. Overall, there was a greater rate of mechanical air extract than supply.

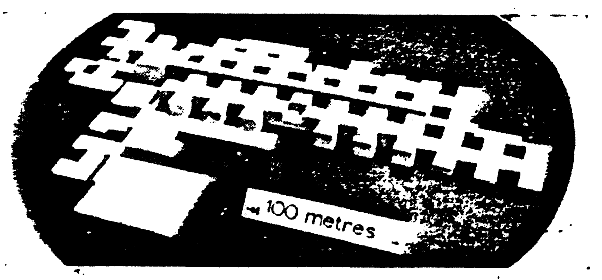

Fig. 6 Location of ward block shown on hospital model

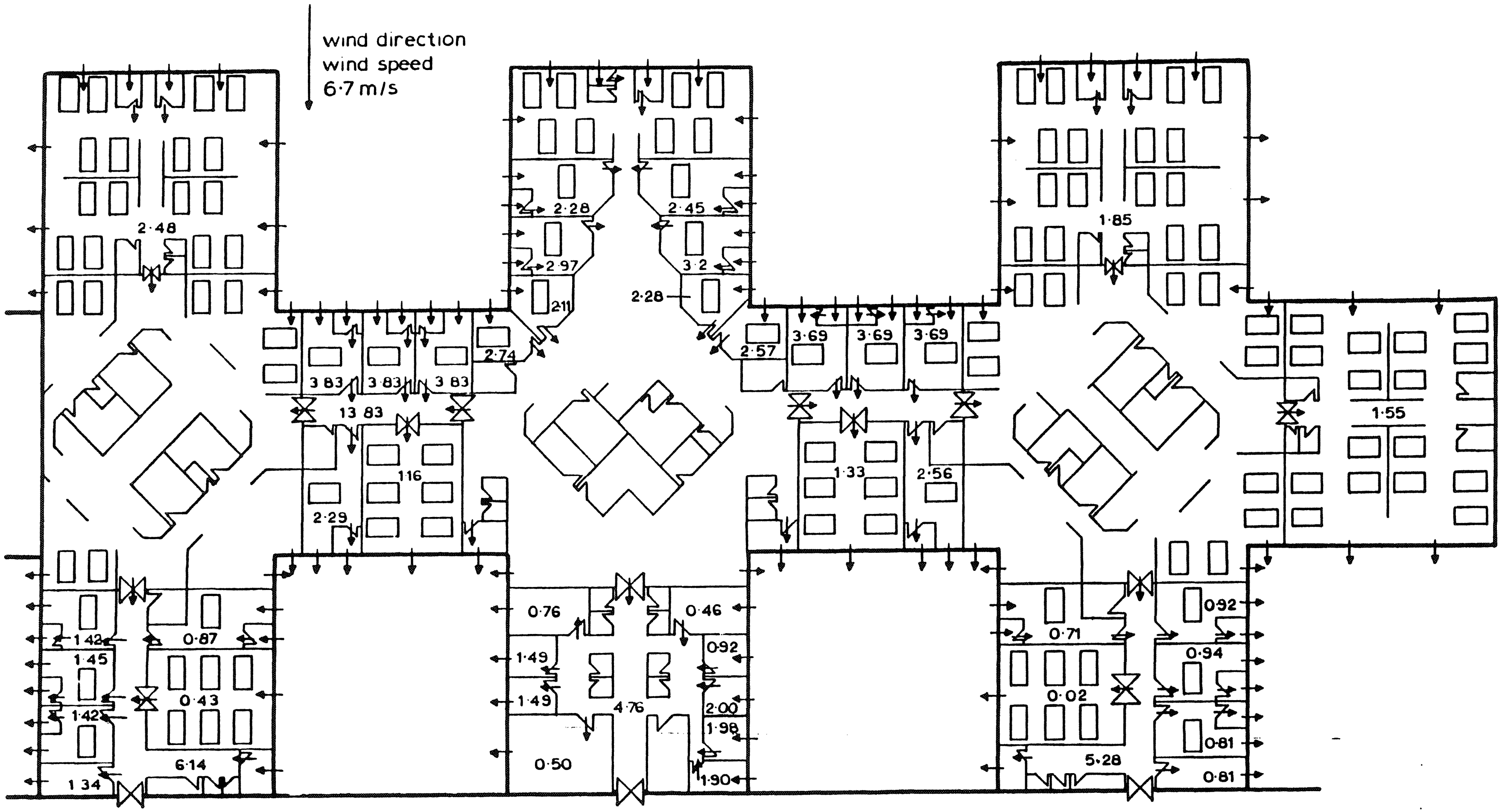

Fig. 7 Ward area (adult acute) plan and calculated ventilation rates

the wind acting in opposition to the flow produced by the mechanical ventilation. As curves *a* and *b* of Fig. 9 show, at the higher wind speeds, complete reversal of flow occurs, so that air passes from the corridors into the wards and then outside (exfiltration). Curves *c* and

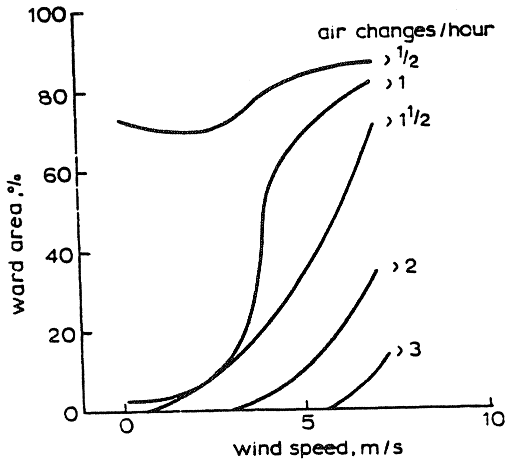

Fig. 8 Ventilation in ward areas (adult acute)

d (Fig. 9) demonstrate the effect in the externally located single-bed wards where the natural ventilation was in the same direction as the mechanically induced ventilation.

The 6-bed wards were situated either:

- with windows on a leeward face within a courtyard
- with windows on a face parallel to the wind direction and within a courtyard.

The curves of ventilation rate related to wind speed are plotted in Fig. 10. They show similar characteristics to curves *a* and *b* for single-bed wards except that the 6-bed ward's ventilation was significantly lower.

Whole hospital ventilation

The results described above relate to only a variation in wind speed and to one wind direction. To assess the overall natural ventilation performance it was necessary to examine the frequencies of occurrence of various combinations of wind speed and direction. On considering the whole hospital, it was found that, because of its elongated shape, crosswinds produced substantially more ventilation than end-on winds.

Meteorological data was thus analysed to establish the proportion of time winds occurred at various speeds and from the various directions in the quadrants corresponding to cross- and end-on orientations (Fig. 11). This was done only for outdoor temperatures less than 10° C because it was assumed that, at high temperatures, it would be possible to increase ventilation by opening windows wider than the assumed 12·5 mm without causing discomfort from cold draughts. Fig. 11 shows the resulting plot for the Birmingham site of percentage time against wind speed, which indicates that the occurrence of crosswinds was similar to that of end-on winds. The mean line was used for the succeeding analysis.

From the graphs it may be noted that the proportion of the time that the wind speed exceeded zero was 50%. The other half of the time consisted of 10% calm and 40% in excess of 10°C.

Using this wind data and the computed ventilation rates of the whole hospital for both cross and end-on winds at various speeds, the chart in Fig. 12 was derived. The continuous lines show the calculated ventilation performance with all windows slightly (12·5 mm) open. Window closure would, of course, considerably decrease ventilation rates, but opening them may generate intolerable cold draughts at outdoor temperatures below 10° C. This latter effect depends somewhat on the form and capacity of the heating appliances in each room. The postulated effects of increasing the window opening for periods of the year when temperatures are higher than 10° C are shown as dotted lines.

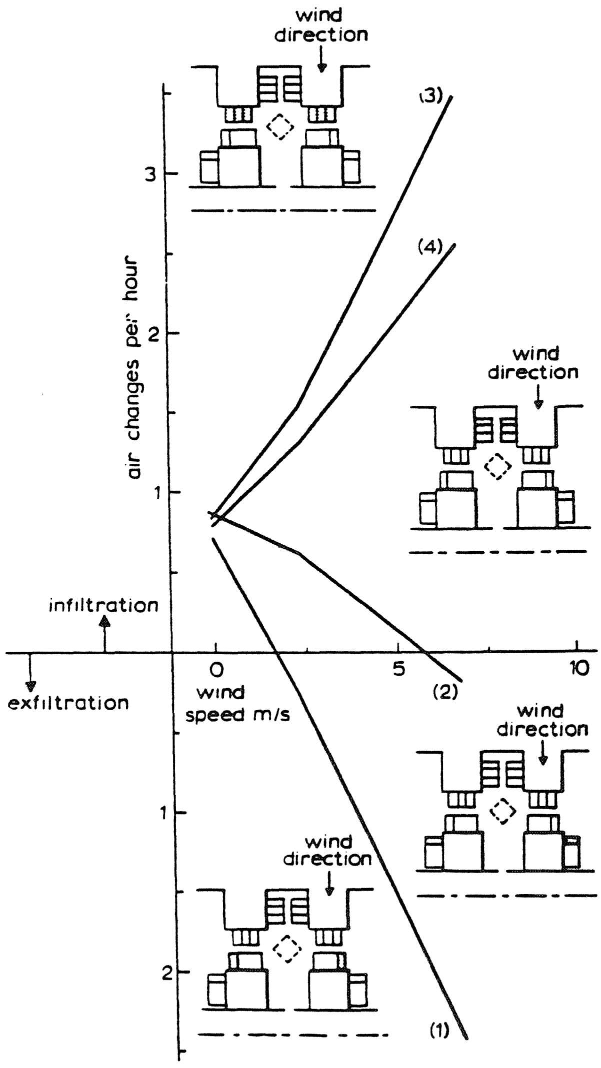

Fig. 9 Single-bed ward ventilation (adult acute)

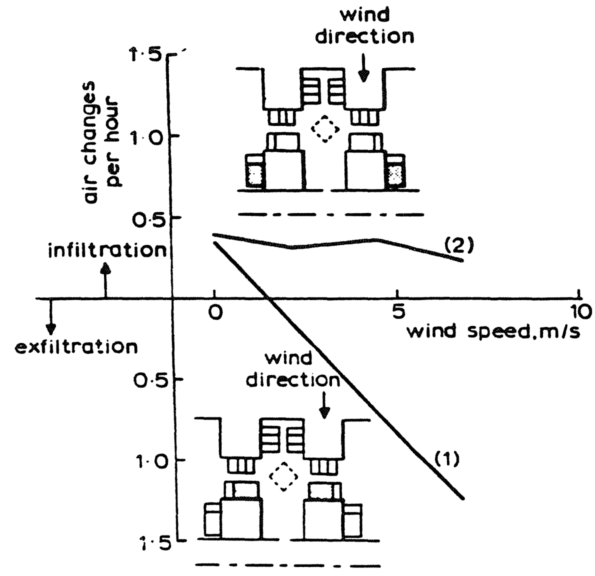

Fig. 10 Six-bed ward ventilation (adult acute)

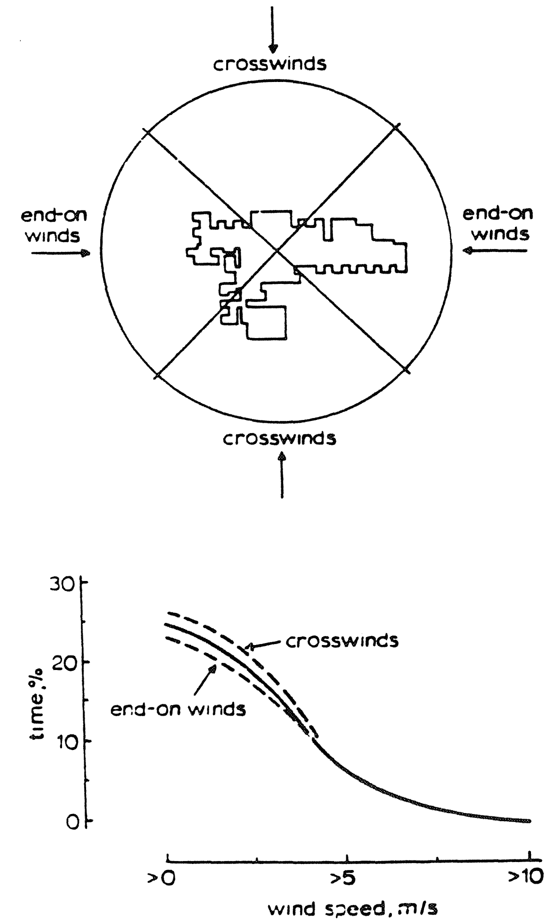

Fig. 11 Frequency curve of wind speeds

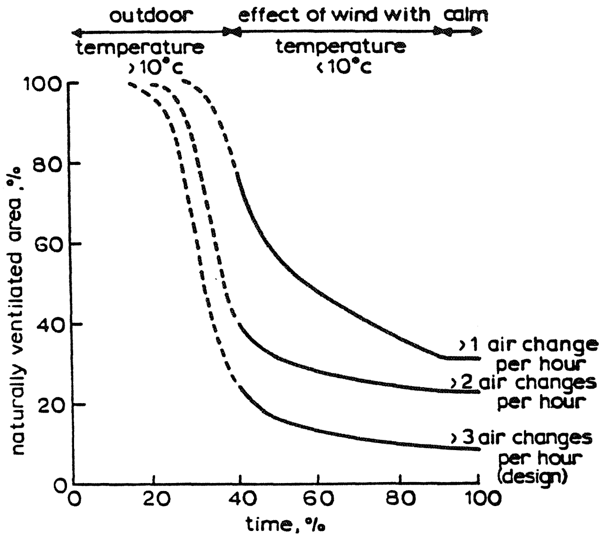

Fig. 12 Natural ventilation performance of a four-storey Harness hospital sited at Birmingham

The chart indicates, for example, that only 50% of the naturally ventilated area of the hospital will have a ventilation rate greater than 1 air change/h for about 45·5% of the time. Similarly, it may be predicted that, for 70% of time, natural ventilation rates of greater than 1 air change/h will occur in only 40% of the hospital, rates greater than 2 in 25% of the hospital and rates greater than 3 in about 10% of the hospital.

Although 2 air changes/h may be considered an acceptable rate of ventilation for normal circumstances, it has been suggested* that 3 air changes/h is more appropriate for hospital wards. It is clearly predicted from the above results that natural ventilation rates will be below this minimum acceptable for much of the time.

The results of this theoretical study thus reveal the general inadequacy of wind forces to produce consistently adequate levels of ventilation in large deep-plan hospital buildings. It would therefore appear necessary to employ mechanical ventilation, at least in areas where the maintenance of fresh-air supplies at all times is important.

The use of the ventilation-prediction technique has ensured that the opportunity for making the provision of mechanical ventilation was available while the buildings were still in the design stage.

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WARD LOCATION

(*a*) With windows on a leeward face within a courtyard
(*b*) With windows on a face parallel to the wind direction and within a courtyard
(*c*) With windows on a windward face
(*d*) With windows on an external face parallel to the wind direction.

*British Standard Code of Practice CP3, 1950, Chap. 1 (c).