NATURAL INFILTRATION ROUTES AND THEIR MAGNITUDE IN HOUSES -

PART 1 - PRELIMINARY STUDIES OF DOMESTIC VENTILATION

by P R Warren

SUMMARY

A supply of fresh air is necessary in any dwelling to ensure a comfortable, safe and hygenic environment, but the heat loss to this air, during the heating season, may represent a substantial proportion of the total heat loss. This points to the need for greater control of domestic ventilation, either by using a mechanical system or by better design for natural ventilation. This paper touches upon both of these possibilities. A simple method is given for assessing approximately the possible reduction in heat loss achieved by the use of a mechanical ventilation system. The first results of field measurements of natural ventilation in six unoccupied houses are described.

Department of the Environment

February 1976
PD 28/76

This paper is to be published in Proceedings of Conference 'Controlled Ventilation - its contribution to lower energy use and improved comfort' Aston University.

ES 4/74
A 113.5.14

SYMBOLS

A	=	Area of ventilation opening	m^2
Ar	=	Archimedes number (defined as $\sqrt{\Delta\theta gh/\overline{\theta}U}$)	-
C_p	=	Pressure coefficient (defined as $(p-p_a)/\frac{1}{2}\rho U^2$)	-
c	=	Thermal conductivity of air	J/kg^{o}K
g	=	Acceleration due to gravity	m/s^2
H_M	=	Ventilation heat loss with mechanical system	J
H_N	=	Ventilation heat loss with natural system	J
h	=	Vertical distance between openings	m
K_d	=	Constant (defined in the text)	
K_e	=	Constant (defined in the text)	
n	=	Frequency at which a given wind speed is exceeded	%
p	=	Static pressure at a surface	N/m^2
p_a	=	Static pressure in the free wind	N/m^2
Q	=	Volume flow rate of fresh air	m^3/s
Q_B	=	Volume flow rate of fresh air	m^3/s
Q_D	=	Design volume flow rate of fresh air	m^3/s
Q_T	=	Total volume flow rate of fresh air	
Q_w	=	Volume flow rate of fresh air due to wind	
t	=	Time	s
t_p	=	Time period for integration of heat loss rate	s
U	=	Reference wind speed (measured at 10 m in open country - as given by Met. Office)	m/s
U_e	=	Equivalent wind speed	m/s
U_n	=	Wind speed exceeded for n% of time	m/s
Δ	=	Difference between two values of the same variable (eg ΔC_p equals $C_{p_w} - C_{p_l}$)	
ρ	=	Density of air	kg/m^3
θ_i	=	Temperature of air inside house	^oC
θ_e	=	Temperature of external air	^oC

NATURAL INFILTRATION ROUTES AND THEIR MAGNITUDE IN HOUSES - PART 1 - PRELIMINARY STUDIES OF DOMESTIC VENTILATION

by P R Warren

1. INTRODUCTION

A supply of fresh air is necessary in any dwelling to ensure a comfortable, safe and hygenic environment. In the past, before the recent rapid increase in the price of fuels it was only necessary to ensure that a minimum level of ventilation was provided. A reasonable value for this based upon normal domestic requirements is 50 l/s. The additional requirement now is to ensure, as far as possible, that no more than the minimum is supplied during the heating season in order to minimise the heat loss and the consequent consumption of fuel. It is estimated that some 20 - 40% of the heat input to the average house is required to account for the ventilation loss. This emphasises the need for greater control of domestic ventilation and this may be achieved in two ways;

(i) By the use of mechanical ventilation supplying the required quantity at a constant rate.

(ii) By better design for natural ventilation.

This paper touches upon aspects of both of these approaches. In the first part an estimate is made of the relative reduction in heat loss over a period during the heating season by using mechanical rather than natural ventilation. In the second part the preliminary results of field measurements of ventilation rates in six houses are presented. These measurements form part of a larger programme of measurements which it is hoped will not only provide up to date data on ventilation rates in the current housing stock, but will also, used in conjunction with computer-based prediction procedures, be used to provide a basis for better natural ventilation design.

2. MECHANISMS OF NATURAL VENTILATION

Although other mechanisms, due to both turbulent velocity and pressure fluctuations exist and require further investigation, the main mechanisms giving rise to natural ventilation are due to mean pressures created by;

(i) Wind

(ii) Buoyancy (or stack effect).

The pressure differences created across openings in the building fabric and between rooms within the building by these agencies, generate a pattern of airflow into and through the building. If the relationships between the applied pressure difference and flow rate are known for these flow paths then in principle the ventilation rate of each room can be calculated. However, f any but the simplest building the use of a digital computer is required t solve the large number of non-linear equations which result from the analysis

As a basis for comparing natural and mechanical ventilation and for interpret the results of full-scale measurements it is useful to consider a simplified model of a house, Figure 1.

For this simple model the magnitudes of the ventilation rates due to wind and buoyancy acting separately are as follows:

(i) Wind

$$Q_w = \sqrt{2}\, C_D A U (\Delta Cp)^{\frac{1}{2}} \qquad (1)$$

where C_D is the discharge coefficient (= 0.61)

A is the area of each of the openings

U is the reference wind speed

ΔCp is the difference in pressure coefficient between the two faces of the building.

ΔCp will depend upon the wind direction and the degree of shelter of building For an unsheltered building with the wind normal to one face it will have a value of approximately 1.0; for a sheltered building the value may be nearer

(ii) Buoyancy

$$Q_B = 2\, C_D A \sqrt{\frac{\Delta\theta g h}{\bar{\theta}}} \qquad (2)$$

where $\Delta\theta$ is the mean temperature difference between internal and external air

$\bar{\theta}$ is the absolute temperature

h is the vertical distance separating the centres of the openings.

It is useful to express equations (1) and (2) in dimensionless terms and also to introduce the dimensionless Archimedes number, Ar defined as

$$Ar^{1/2} = \sqrt{\frac{\Delta\theta g h}{\bar{\theta} U^2}} \qquad (3)$$

Thus, for wind

$$\frac{Q_w}{C_D A U} = (2\, \Delta Cp)^{\frac{1}{2}}$$

for buoyancy

$$\frac{Q_B}{Ar^{1/2} C_D A U} = 2$$

In any real situation buoyancy and wind will act simultaneously. Certainly this will be the case in the heating season. Even for this simple single-celled example the solution for both mechanisms acting together is complex.

The flow rate Q_T, under these circumstances has been calculated and is plotted, in Figure 2 using the dimensionless co-ordinates

$$\left[\frac{Q_T}{Ar^{1/2} C_D A U}\right] \quad \text{and} \quad \left[\frac{(\frac{1}{2}\,\Delta Cp)^{\frac{1}{2}}}{Ar}\right]$$

Also superimposed on the solution in Figure 2 are the lines representing (1) wind alone

$$\left[\frac{Q_w}{Ar C_D A U}\right] = 2\left[\frac{(\frac{1}{2}\,\Delta Cp)^{\frac{1}{2}}}{Ar}\right]$$

and (ii) buoyancy alone

$$\left[\frac{Q}{ArC_DAU}\right] = 1$$

It is clear that buoyancy dominates for values of $\frac{(\frac{1}{2}\,\Delta Cp)^{\frac{1}{2}}}{Ar} < 1$ and equation $4(b)$ is a good approximation to the exact solution. For values of $(\frac{1}{2}\,\Delta Cp)^{\frac{1}{2}}/Ar > 1$ wind dominates and equation $4(a)$ is a good approximation. This may be stated in a more useful way by considering the value of wind speed, U_e, at which the volume flow rate due to wind and due to buoyancy are equal, ie at the point of intersection,

$$(\tfrac{1}{2}\,\Delta Cp)^{\frac{1}{2}} = Ar$$

ie

$$\frac{U_e}{\sqrt{\Delta\theta}} = \sqrt{\frac{2.gh}{\overline{\theta}.\Delta Cp}} \qquad (4)$$

Since $\overline{\theta}$ will vary only very slightly and may be taken to be equal to 300

$$U_e = K_e\,\sqrt{\Delta\overline{\theta}} \qquad (5)$$

where $$K_e = 0.25\sqrt{\frac{h}{\Delta Cp}}$$

Now K_e depends upon h and ΔCp only, and not upon the magnitude of the open area, provided that this is distributed as in Figure 1. h represents the height between openings and, for normal dwellings, will be in the range 3 - 6 m. ΔCp depends upon wind direction and the influence of the surroundings For an exposed building with the wind perpendicular to one face $\Delta Cp \doteqdot 1.0$, for a sheltered building, or for the wind mainly parellel to faces containing the openings ΔCp could be as low as 0.1. Taking these variations into account K_e would be expected to be in the range

$$0.5 < K_e < 2.0$$

Measurements made by Dick (1) for instance in a two-storey detached house enable a value of K_e of 0.85 to be determined. In this case K_e appears to be fairly independent of wind direction and the relatively high value reflects the sheltered situation of the house. Some measure of the effect of other than the equal distribution of area, is indicated in Figure (1) may be obtained by considering the same simple layout but with the following alterations to the open areas;

(i) Openings 1 and 3 *three* times as large as 2 and 4.

(ii) Openings 3 and 4 *three* times as large as 1 and 2.

The definition of K_e, in each case, then becomes;

(i) $$k_e = 0.12 \sqrt{h/\Delta Cp}$$

and,

(ii) $$K_e = 0.52 \sqrt{h/\Delta Cp}$$

Again these agree qualitatively with Dick's results. In the house with three bedroom vents open, approximately equivalent to (i), K_e was reduced from 0.85 to 0.6. With predominantly leeward vents open, both on the ground as well as the first floor, a situation equivalent to (ii) K_e was increased to 1.0.

Rayment (2) and Caton (3) have shown that the cumulative frequency distribution of wind speed can be expressed in the form of a single curve (Figure 3(a) based upon U_{50}, which is the wind speed exceeded for 50% of the time at any given site. Figure 3(b) shows a contour map of U_{50} for the United Kingdom. For instance in order to determine the speed exceeded for 60% of the time near London can be determined by finding U_{50} from Figure 3(b), which in this case is equal to 4.0 m/s, and obtaining from Figure 3(a) that $U_{60}/U_{50} = 0.78$. Thus U_{60} is 3.1 m/s. This provides a basis for natural ventilation design. Equation (1) indicates that for wind acting alone the ventilation rate will be proportional to wind speed. The constant of proportionality is in turn proportional to the areas of opening and to the square root of applied pressure difference coefficient. This latter is a function only of wind direction and may in fact be expected for certain types of dwelling, in particular those with relatively high areas of external wall, to be fairly constant. This was certainly true of Dick's measurements on semi-detached houses at Abbots Langley.

Thus, if the predominant wind direction is taken, the ventilation rate at any wind speed will depend only upon the area of opening and these may in principle be sized to give the design ventilation rate (of say 50 l/s) for the dwelling at a wind speed for the site which is exceeded for a given proportion of time. It follows that the ventilation rate, remembering that buoyancy effects are neglected at this point, will have the same form of cumulative frequency distribution as wind speed, over any period during which ventilation openings remain unaltered, since

$$Q_w = K_d U \qquad \text{where} \qquad K_d = A(\Delta Cp)^{\frac{1}{2}}$$

and

$$Q_D = K_d U_n$$

where Q_D is the design ventilation flow rate

U_n is the speed exceeded for $n\%$ of time

3. VENTILATION HEAT LOSS

If we make two simple assumptions

(i) During the period under consideration, tp, the openings remain fixed

(ii) K_d does not vary with wind direction,

then, the heat lost by natural ventilation H_N is given by,

$$H_N = \rho c \int_o^{tp} Q(\theta i - \theta)dt$$

where θ is the external air temperature and θi is the design internal mean temperature, assumed constant.

Now $$Q = K_d U$$

hence $$H_N = \rho c K_d \int_o^{tp} U(\theta i - \theta)dt$$

H_N may be compared with the heat H_M that would be lost by a 'perfect' ventilation system, ie a system which supplied the design rate throughout the heating period. A full mechanical system would approximate to this

$$H_M = \rho c \int_0^{tp} Q_D(\theta i - \theta)dt$$

$$\therefore H_M = \rho c K_d \int_0^{tp} U_N(\theta i - \theta)dt$$

Thus

$$\frac{H_N}{H_M} = \frac{\int_0^{tp} U(\theta i - \theta)dt}{\int_0^{tp} U_N(\theta i - \theta)dt}$$

whence it can be shown that, provided U and θ are not correlated

$$\frac{H_N}{H_M} = \frac{\bar{U}}{U_n}$$

This comparatively simple expression has only been arrived at after a number of simplifying assumptions, but it has the merit that it enables the relative savings in ventilation heat loss using a 'perfect' mechanical system, to be estimated from the chosen proportion of time that the design rate is exceeded in the natural system, and the mean wind speed which is, in fact, the area beneath the cumulative frequency curve.

Thus far, the effect of buoyancy, as a mechanism of natural ventilation, has been neglected but it can readily be included using the concept of equivalent velocity discussed earlier. With a knowledge of the variation of $\Delta\theta$ during the period of interest an appropriate mean value of U_e may be determined for any appropriate value of K_e. The cumulative frequency curve may then be changed to the form illustrated by Figure 4(b). Clearly the effect of including the effect of buoyancy is to increase $\bar{U}$, and hence to increase the ratio H_N/H_M for constant U_n.

As an example values of H_N/H_M have been determined for a range of values of K_e and n for the three coldest winter months using meteorological data for London, Heathrow. The percentage reductions in heat loss due to ventilation are set out in Table 1. In practice the most likely range of K_e will be 0.5 to 1.0. It should be noted that values substantially above the upper limit of this range lead to values of U_e during the coldest periods larger than that of U_{50} and indicate that for these cases wind speed will not be the major climatic variable determining ventilation rate, as assumed in th foregoing analysis in Section 2. The proportion of circumstances to which this will be applicable is expected to be small but it emphasises the need to interpret the results for values of $K_e > 1.0$ in Table 1 with some care. It is however clear that, provided comparison is made with a natural ventilation system which gives the required flow rate for at least 50% of the time, there will be a benefit from replacing it with a perfect mechanical system, the nearest practical approach to which is an input-extract system. The reduction in heat loss can be of the order of 30 - 40% for values of n and K_e of approximately 60 and 1.0 respectively. In any practical situation this would necessarily be partly offset by the energy consumed by the fan, althoug of course, it would be possible to obtain even greater reductions by the use a heat recovery device, transferring heat from the outgoing to the incoming air. The results determined for this simple example rest on a number of assumptions and limitations, including the following;

(i) That there is no effect on natural ventilation of wind direction.

(ii) That the annual cumulative frequency curve is equally applicable to the three chosen months only.

(iii) Mean monthly temperatures were used.

The approach could be extended readily to take account of these, given the appropriate climatic data, but the order of magnitude of the reductions given in Table 1 would not be expected to be substantially altered.

4. VENTILATION RATES IN DWELLINGS

4.1 General

The foregoing discussion dealt with the rather artificial situation in which was assumed that areas for ventilation could be fixed to give a design rate for a selected proportion of time. In practice many openings are adventitious and although in some cases these can be altered, by sealing or draught-stripping for instance, the occupant cannot readily determine what effect this may have on ventilation rate. In order to provide data on wintertime ventilation rates the Building Research Station is currently carrying out a programme of measurements in unoccupied dwellings. The data will be used to test predictions from computer-based theoretical models and it is also hoped to correlate measured ventilation rates with the results from the simple leakage test procedure described by Skinner (4). Although this programme of measurements has only been under way for a fairly short period of time it is possible to present some interim results and conclusions.

4.2 Techniques and Instrumentation

Ventilation rates were measured using tracer gas technique which has been described in detail by a number of workers. Briefly a quantity of tracer gas, in this case nitrous oxide, is injected into the space under test and the decay in tracer concentration monitored using an infra-red gas analyser and recorded. Provided that incoming air mixes well within the space, which is generally the case in the conditions of air movement found within a dwelling, the decay is exponential with a time constant which is the inverse of ventilation rate. Local wind speed and direction and also temperatures within and outside the dwellings were also measured and logged on paper tape for subsequent analysis by computer.

Measurements have been made in six dwellings, reasonably typical of modern housing stock of which brief details are given in Table 2.

4.3 Whole House Ventilation Rates

Because of the limited period of time, usually about one month, for which each of the houses was available for testing it was not possible to employ the technique described by Dick (5) for the determination of whole-house ventilation rates which would have required the simultaneous liberation of tracer gas into all rooms within the house. Instead two other methods were used. In the first, individual room rates were measured and from a knowledge of the air flow paths and directions through the house, determined by observation of a smoke tracer, it was possible to build up the whole house ventilation rate from the air entering rooms on the windward side. This technique could only satisfactorily be used where air entering one windward room did not pass into an adjoining windward room. The second method was to make the house into one large space by opening internal doors and installing mixing fans usually in the door-ways to facilitate mixing. This method has the advantage that it is rapid but may be criticised on the grounds that it creates unrepresentat conditions within the house. However provided the mixing fans were arranged t ensure that they did not create air jets which would impinge on any openings i the external wall the arrangement would be expected to give the correct ventil tion rates for a house with internal doors wven only slightly open since the air flow rates would be determined by the resistance of the smaller openings i the external wall. Even with internal doors closed the results should not be substantially in error because of the generally poor fit of internal doors. It should also be noted that temperature differences between rooms in the house will be substantially reduced. This would only be expected to have a significant effect when wind speeds are low and buoyancy forces dominate. Eve then it is the <u>mean</u> internal temperature which is the most important factor i determining whole house ventilation rate, and this will be the same in both with and without

The first method was used in determining whole house rates for houses *C* and *D* and the second method for houses *D*, *F*, *G*, *H* and *J*. The results for house *D* therefore provide a useful comparison between the two methods. Figure (5) shows the variation of ventilation rate with wind speed for the predominant wind direction. The results using the first method (with internal doors closed) lie very close to those determined using the second method. Although these results are for a single case only the comparison lends confidence to th use of the more rapid method for measuring whole house ventilation rates.

Table 3 shows the ventilation rate achieved at the mean wind speed for each site. These values were obtained by fitting the best straight line through the data, plotted against the major variable, wind speed, as in Figure (5), and reading off the ventilation rate applicable to the mean wind speed for the site. Clearly this method gives a value weighted towards the particular distribution of wind direction and temperatures occurring during the period of testing, which may not be typical of the distribution which would apply during other periods of interest such as the full heating season. However in lieu of the more detailed analysis it is suggested that these estimates will not err substantially.

Although there is a wide variation in whole house ventilation rates shown in Table 3, from 0.3 to 1,35 these all lie well below the value of 2.0 determined by Dick (5) from measurements on semi-detached houses at Abbots Langley. Of the present houses only H and J were fitted with flues and these had been sealed off whereas the Abbots Langley house had both flues as well as a number of purpose built ventilation openings into the roof space. This is almost certainly the main reason for the substantial difference between the two sets of results. In three of the houses, *D*, *H* and *J*, the ventilation flow rates were well below the suggested requirement of 50 l/s. Although these results are only a tiny sample, and care must be taken in generalisation at this stage, there is a clear indication that the suspected reduced ventilation rates in modern, as opposed to earlier housing, is well founded.

4.4 Individual Room Ventilation Rates

At each site ventilation rates were measured in individual rooms, with internal doors closed. These have been analysed in a similar way to the whole house rates the ventilation rates applying at the mean wind speed are listed in Table 4. Because of the method of measurement there is no distinction in these results between the situation when the room was ventilated entirely with air from outside and when some of the air had passed through other parts of the house. This is immaterial if the results are to be compared with some form of predictive method but from the point of view of satisfying ventilation requirements it should be born in mind that some of the air entering the room may already be contaminated and these results would give an optimistic assessment of the level of ventilation.

As might be expected the levels of ventilation for rooms given in Table 4 for each of the six houses reflect the same trends as the whole house rates given in Table 3. As a basis for discussed it is useful to compare these with the levels specified in the appropriate Code of Practice - CP 3, Chapter 1(c) - 'Ventilation', and other bases for ventilation requirements. The requirements of CP 3 Ch.1(c) are summarised in Table 5.

In living rooms the required flow rate is based upon the need to remove body odour and depends upon the density of occupation. Taking the size of the dwellings into account a reasonable level of offucpation would seem to be four persons yielding a requirement of about 20 l/s. It is clear that this is achieved in house *C* and very nearly in house *J* but that in the remaining houses some window opening would be required for much of the time to achieve this level.

Similarly, except in houses *C* and *F*, the majority of bedrooms would not be satisfactorily ventilated in accordance with the Code of Practice. Again this recommendation is based upon odour level and nuisance due to odour will depend very much upon the subjective reaction of the occupant. However, Loudon has pointed out the relationship between low ventilation rate and the possible onset of condensation and mould growth in dwellings, in particular in bedrooms, which may often be poorly heated. Although condensation will depend on other factors than ventilation the levels found in houses *D*, *G*, *H* and *J* give rise to some concern.

Kitchens present a particular problem. This area of the house is the main source of many contaminants found in dwellings, particularly moisture from cooking and clothes washing. These, however by their nature are intermittent activities and may be dealt with by high, short-term ventilation rates necessarily supplied by window opening or by the use of an extractor fan. To prevent condensation by this means under typical circumstances requires a flow rate of some 80 l/s (6). The alternative is to allow some water vapour to condense during the production period but maintain a minimum constant level of fresh air supply, sufficient to ensure that it is re-evaporated over a period of time. Gauger & Schule (7) suggest 30 and 15 l/s depending upon whether cooking is by gas or electricity. CP 3 - ch. 1(c) recommends 16 l/s without making the basis of this figure clear. The levels measured are probably satisfactory, except in the case of house *H* which has a very low rate of 6 l/s, although some window opening would be required in houses *F*, *G*, and *J*.

4.5 The Effect of Window Opening

Due to limited time it was not possible to examine the effect on ventilation rate of window opening in detail. However, in order to obtain a measure of the controllability of ventilation using openable windows in modern houses the effect on room ventilation rates of opening the smallest available window in the room to its *first fixable position* was measured. In all cases internal doors and other windows were closed, except for one other window similarly opened in the opposing room on the other side of the house. The change in ventilation rate, at the site mean wind speed, are given in Table 6. The increase in all cases is substantial, at least two-fold and, on average, four-fold. The actual figures only have relevance to the particular houses measured, but their importance lies in reflecting the poor control that openable windows provide over natural ventilation in a room.

5. CONCLUSIONS

These results form only part of a continuing programme of research on domestic ventilation, which will be reported on more fully in due course. It is possible however to draw some interim conclusions:

(i) If over a particular period of time the size and distribution of openings in a house is such that the required ventilation rate is supplied for 50%, or a larger percentage of the time, then there will be a theoretical benefit in reduced ventilation heat loss achieved by supplying this air flow rate by an input-extract mechanical system, even without heat exchange. The magnitude of the reduction will vary with the particular application but as an example, for a typical house in the London area the saving over the three main winter months could be 30 to 40% in comparison with a natural ventilation system giving a desired rate for 60% of the time.

(ii) Whole house ventilation rates were measured in six houses and were found to lie in the range 0.3 to 1.35 air changes per hour at mean wind speed. These were lower than the rates, typically 2.0 air changes per hour, measured by Dick in housing built in the immediate post-war period, and in three of the houses the volume flow rates were found to be well below the suggested minimum value of 50 l/s at mean wind speed.

(iii) In many cases individual room ventilation rates were found to be well below the requirements suggested in British Standard Code of Practice CP 3 Chaper 1(c) - 'Ventilation', particularly in bedrooms and living rooms.

(iv) The increase in ventilation rate in rooms when a window was opened to its first fixed position was found to be substantial, on average four times the level with the window closed. This reflects the poor control that openable windows have over natural ventilation.

ACKNOWLEDGEMENTS

The author wishes to thank B C Webb, Mrs L Parkins and G F Powell who were responsible for the field measurements and much of the subsequent data analysis.

The work described has been carried out as part of the research programme of the Building Research Establishment of the Department of the Environment and this paper is published by permission of the Director.

REFERENCES

1. Dick J B, 'Ventilation Research in Occupied Houses' JIHVE Vol.19 October 1951 pp 306-326.

2. Rayment R, 'Energy from the Wind' to be published.

3. Caton P G F 'Standardised maps of hourly mean wind speed over the United Kingdom and some implications regarding wind speed profiles', to be published in the Proceedings of the 4th International Conference on Wind Effects on Buildings and Structures. London 1975.

4. Skinner N P 'Natural Infiltration Routes and their Magnitude in Houses' - Part 2, to be published in the Proceedings of the Conference on Ventilation - Its Contribution to Lower Energy Use and Improved Comfort. Aston University 24th September 1975.

5. Dick J B 'Experimental studies in natural ventilation of houses'. JIHVE Vol. 17 1949 pp 420-466.

6. Loudon A G 'The effects of ventilation and building design on the risk of condensation and mould growth in dwellings'. Building Research Station Current Paper CP 31/71 October 1971.

7. Gauger R & Schule W 'Ventilation Systems in Dwellings', BRS Library Communication No. 901, June 1959.

TABLE 1 - PERCENTAGE REDUCTION IN VENTILATION HEAT LOSS ACHIEVED BY USING A 'PERFECT' MECHANICAL SYSTEM IN PLACE OF NATURAL VENTILATION.

(Based on meteorological data for London, Heathrow)

Value of K_e	Design wind speed				
	U_{30}	U_{40}	U_{50}	U_{60}	U_{70}
0.0	-35%	-15%	3%	23%	42%
0.5	-28%	-9%	7%	27%	45%
1.0	-11%	5%	19%	36%	52%
1.5	8%	22%	34%	48%	61%
2.0	27%	37%	47%	58%	69%

TABLE 2 - DESCRIPTION OF HOUSES TESTED

Site	Description	Year built	Volume (m^2)
C	3 bed. end terrace	1972	168
D	3 bed. semi-det.	1971	197
F	3 bed. end terrace	1975	200
G	4 bed. end terrace	1975	217
H	3 bed. semi-det.	1957	254
J	3 bed. semi-det.	1957	249

TABLE 3 - WHOLE HOUSE VENTILATION RATES

Site	Ventilation Rate at mean wind speed	
	air changes per house	l/s
C	1.25	60
D	0.55	30
F	1.35	75
G	0.80	48
H	0.30	21
J	0.50	35

TABLE 4 - INDIVIDUAL ROOM VENTILATION RATES AT MEAN WIND SPEED

House	*C*	*D*	*F*	*G*	*H*	*J*
Living Room	33 (1.9)	3 (0.4)	5 (0.4)	9 (0.7)	10 (0.5)	17 (0.8)
Kitchen/diner	32 (3.2)	17 (1.5)	12 (1.3)	13 (1.3)	-	-
Kitchen	-	-	-	-	6 (0.9)	12 (1.7)
Bedroom 1	6 (0.8)	3 (0.4)	9 (1.2)	5 (0.7)	6 (0.5)	5 (0.4)
Bedroom 2	8 (1.6)	2 (0.3)	10 (1.2)	5 (0.7)	3 (0.3)	4 (0.4)
Bedroom 3	13 (3.8)	3 (0.8)	5 (1.1)	5 (1.2)	3 (0.7)	2 (0.4)
Bedroom 4	-	-	-	3 (0.6)	-	-
Bathroom	3 (1.4)	4 (2.4)	8 (3.5)	7 (3.0)	2 (0.6)	3 (1.5)
W.C	-	5 (4.8)	2 (2.3)	3 (3.0)	1 (0.7)	1 (1.1)

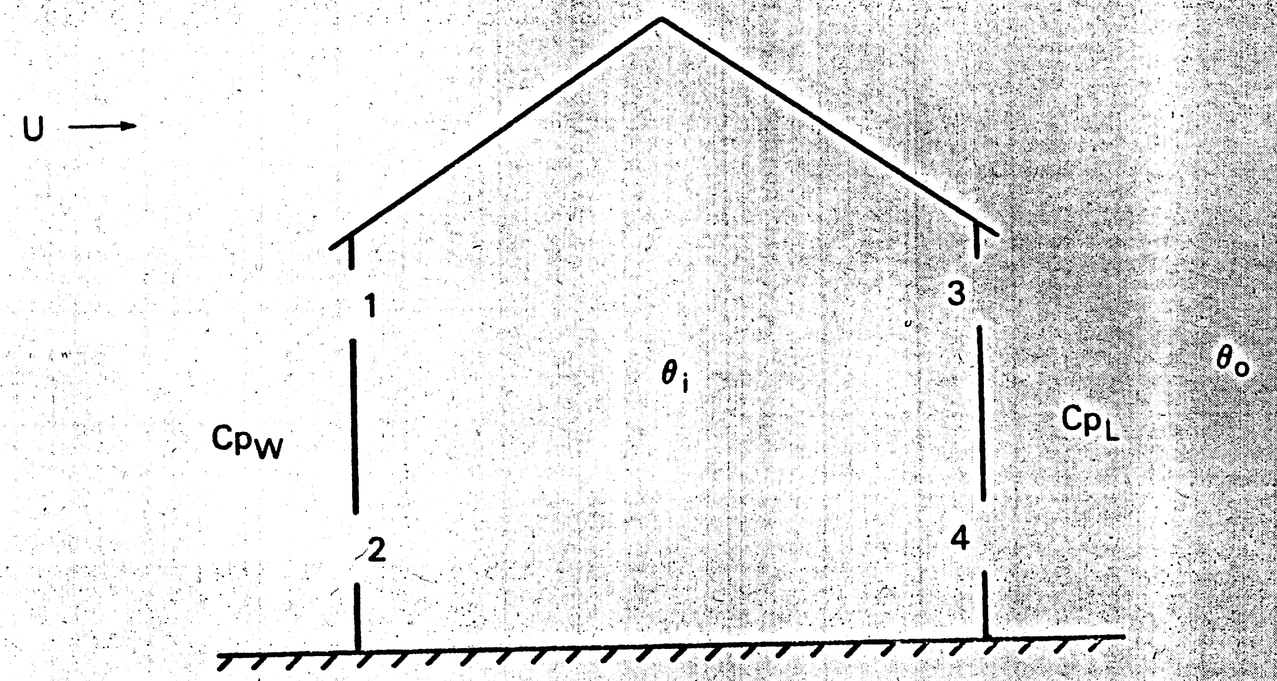
n.b. All flow rates are in l/s. Figures in brackets are the appropriate equivalents in air changes per hour.

TABLE 5 - RECOMMENDED MINIMUM RATES OF FRESH-AIR SUPPLY FOR HOUSES AND FLATS, GIVEN BY BRITISH STANDARD CODE OF PRACTICE, CP 3 CHAPTER I(c) - 'VENTILATION'

Room	Recommended fresh air supply rate
Living rooms & Bedrooms	
8.5 m^3 per person	5.7 l/s per person
11.3 m^3 per person	4.7 l/s per person
14.2 m^3 per person	3.3 l/s per person
Kitchens	15.7 l/s
Bathrooms	2 air changes per hour
W.Cs	2 air changes per hour

TABLE 6 - THE EFFECT OF ROOM VENTILATION FLOW RATES (l/s) OF OPENING ONE WINDOW IN THE ROOM TO ITS FIRST POSITION

Room	House *D*		House *F*		House *G*	
	closed	open	closed	open	closed	open
Living Room	3	15	9	16	9	21
Kitchen/diner	17	26	12	51	13	33
Bedroom 1	3	20	9	16	5	25
Bedroom 2	2	26	10	33	5	24
Bedroom 3	3	18	5	11	5	15
Bathroom	4	41	8	16	7	19
W.C.	5	37	2	11	3	7


U
1
2
3
4
Cp_W
θ_i
Cp_L
θ_o

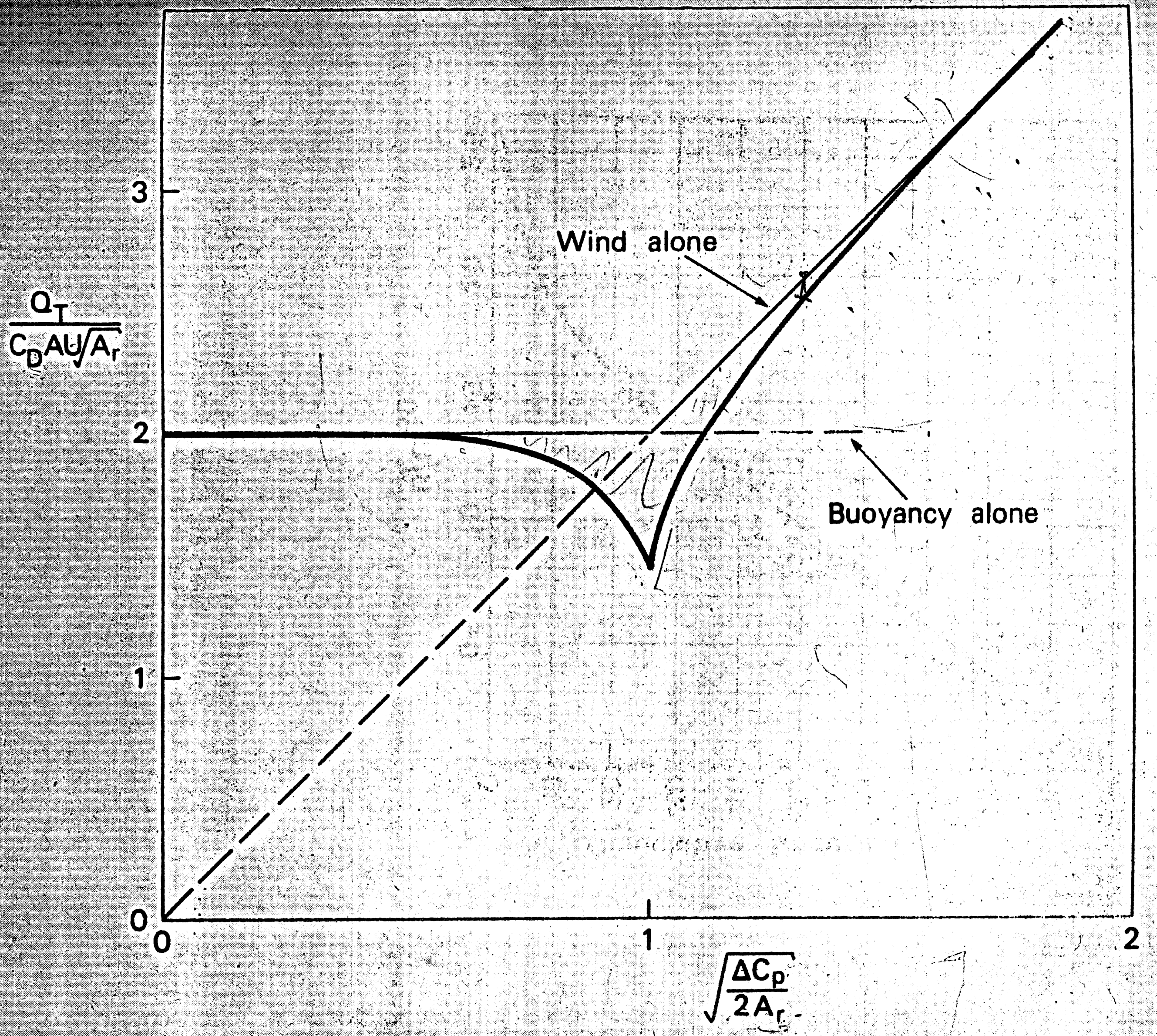


Figure 2 A comparison of total ventilation rate with the rate due to buoyancy and wind acting alone

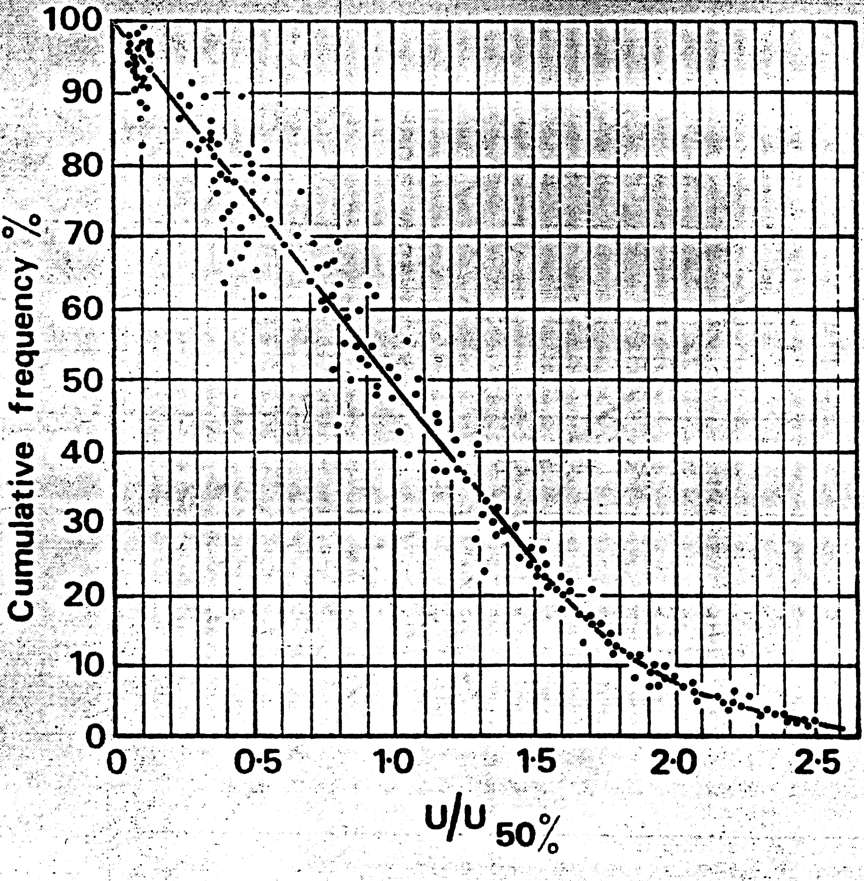
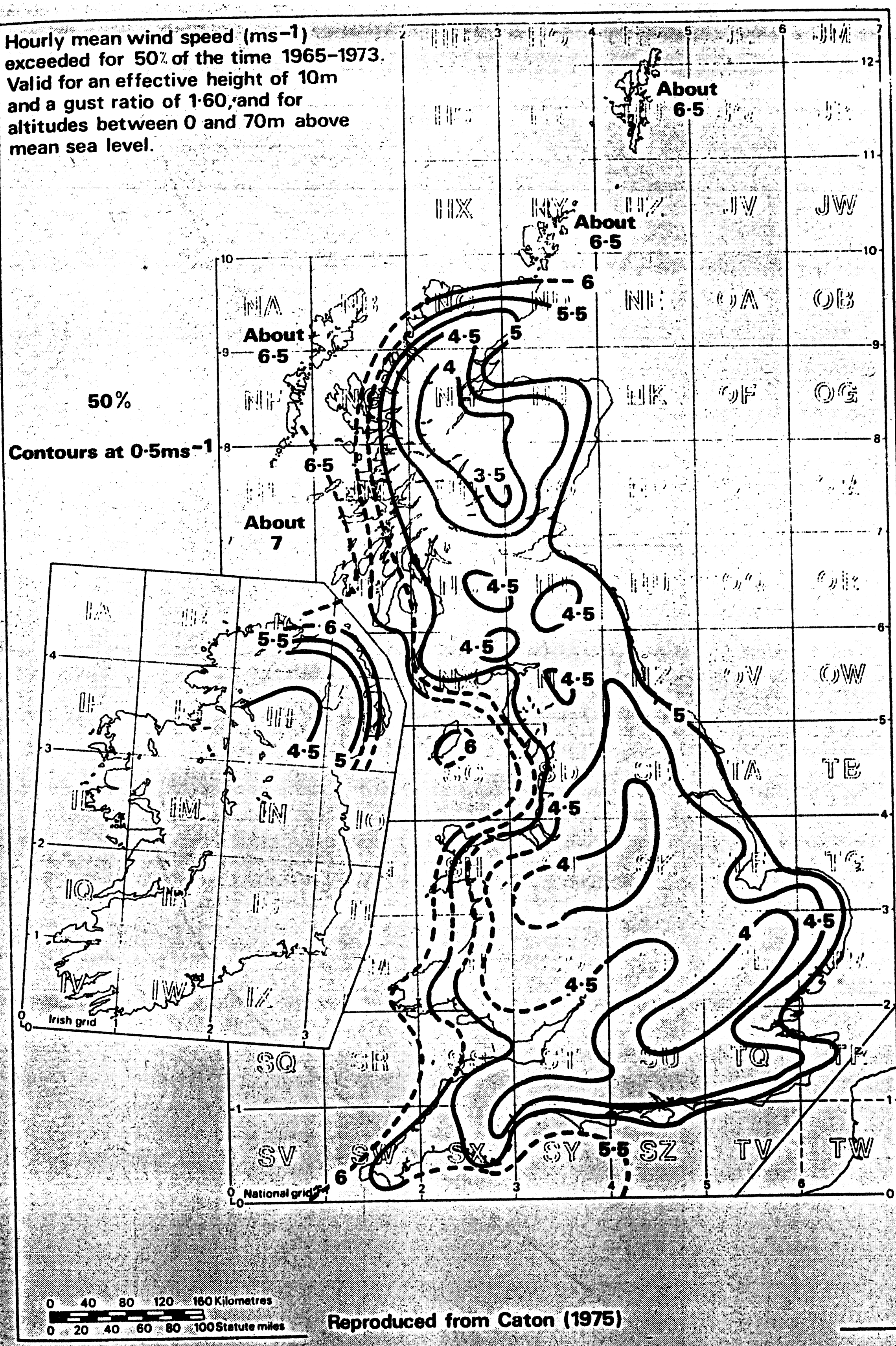
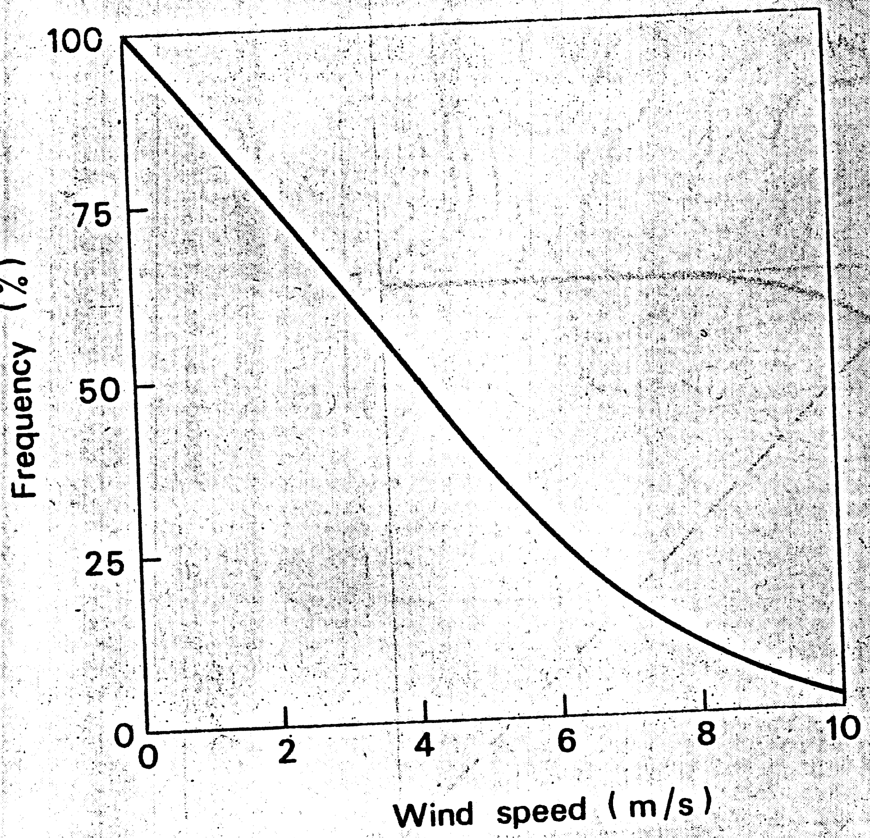


Figure 3(a) Cumulative frequency distribution of U/U_{50} for 35 observing sites in the UK

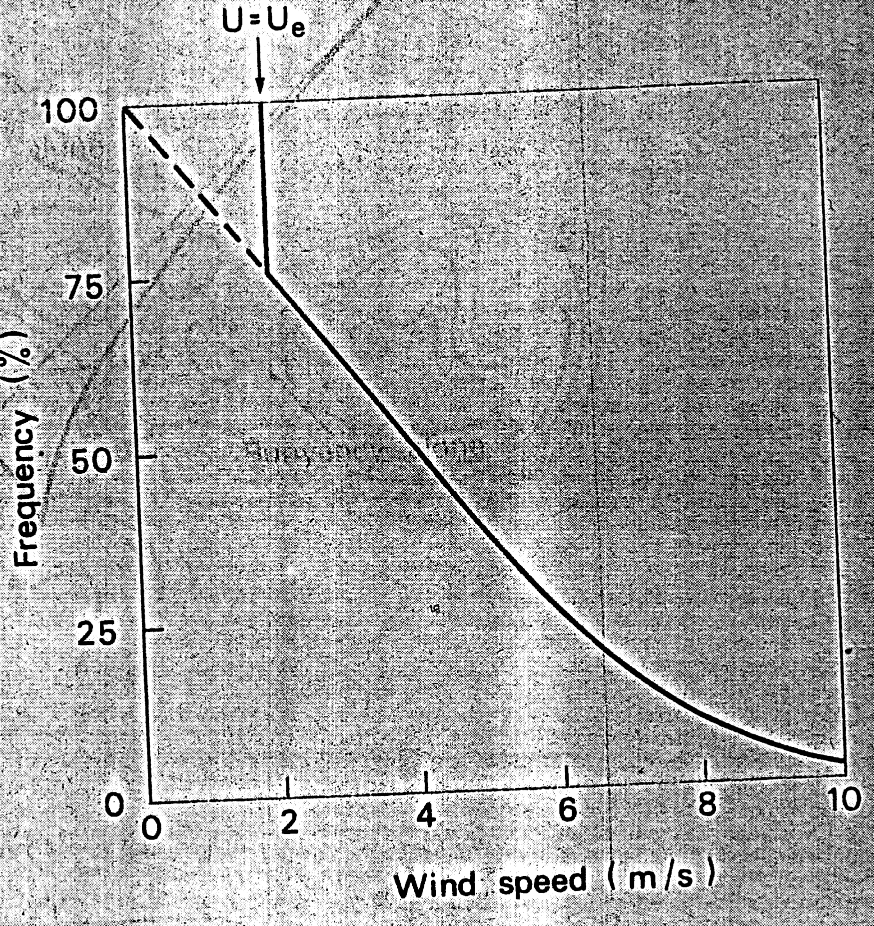


Reproduced from Caton (1975)

Figure 3(b) Contours of U_{50} for the United Kingdom



a) Wind alone



b) Wind + buoyancy

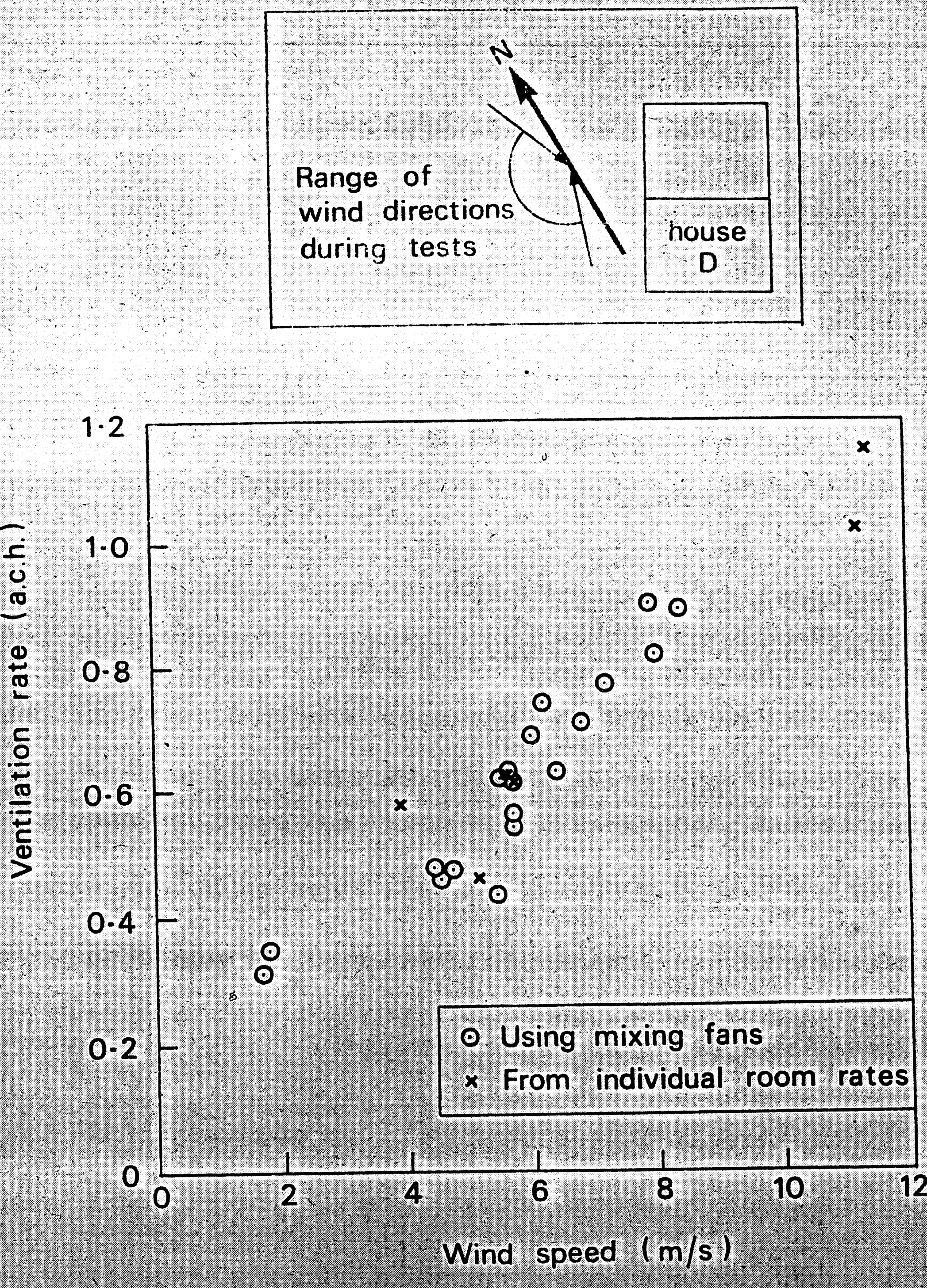


Figure 5 Whole house ventilation rate v wind speed House D