WEATHER DATA FOR AIR INFILTRATION AND VENTILATION CALCULATIONS

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Wind and temperature provide the motivating force behind air infiltration and can also significantly influence the performance of mechanical ventilation systems. In this paper, the interpretation of CIBSE Weather Year Data for both ventilation and ventilation related heat loss calculations is described. A numerical calculation technique to estimate air change rates is introduced and is used to illustrate the application of weather data.

INTRODUCTION

Fresh air is essential, both to meet the respiratory needs of occupants and to dilute and disperse contamination within buildings. However, incoming air imposes a heating (or cooling) load on the building and therefore represents a source of building energy loss. Incoming fresh air may also introduce discomfort in the form of excessive draughts or depressed room air temperatures. Furthermore, increasing concern is being shown towards indoor air quality in buildings and hence much more needs to be known about the transient effects of climate on the performance of building ventilation.

The rate of air change is primarily governed by the airtightness of the building and by the magnitude of pressure imbalances developed across envelope penetrations. It is also influenced by the distribution of leakage paths, the aerodynamic flow characteristics of openings and internal impedences to air movement. In naturally ventilated structures, the driving force creating the pressure imbalances are entirely due to the climatic influence of wind and temperature, in which case climate plays a fundamental role in the provision of adequate ventilation. In mechanically ventilated buildings, the effect of climate can be minimised by combining the advantages of airtight construction techniques with correctly sized inlets or outlets, or with a balanced supply/extract system. However, it is difficult to justify such methods for many buildings in the United Kingdom and therefore design for natural ventilation is very important. Since there is a substantial variation in climate, both on a diurnal and annual basis, it is most unlikely that a single condition of building porosity can be expected to meet ventilation needs throughout the full range of climatic conditions in the UK. It is therefore desirable to consider the frequency of occurences for which potentially unsuitable conditions prevail. The designer is then in a position to accommodate this risk or make separate provision such as incorporating airtightness measures, providing adjustable vents or installing mechanical ventilation. Ventilation is therefore a vital aspect of building environmental analysis.

The CIBSE Weather Year Data provides one method by which hourly rates of ventilation throughout an entire year may be assessed. It also has the advantage of representing a real weather sequence and, as such, can be used to identify unacceptable risk sequences. Not only does this data assist in air quality design but it also helps in the prediction of both annual and peak energy loads for satisfying ventilation heat loss. The objective of this paper is to illustrate how the CIBSE Weather Year Data may be applied to a simple calculation technique, in order to demonstrate the effect of climate on air change rates. Particular emphasis is devoted to the variability of air change due to weather and to the consequential effect on ventilation heat loss. Methods by which the effects of climate can be controlled are also outlined.

CALCULATION TECHNIQUE

The mathematical representation of airflow through cracks and openings is extremely complex. Consequently it is necessary to make a number of simplifying assumptions which enable the main physical concepts to be retained, yet also enable an acceptable mathematical representation of the flow process to be formulated. The calculation of air infiltration and ventilation is reviewed in detail in the AIVC's Calculation Techniques Guide (Liddament (1)) and therefore only a brief outline is presented below. For a building in which the interior can be assumed to be at a single internal pressure (single zone approximation), the infiltration rate may be determined by defining a set of flow paths to represent the leakage openings in each face of the building. Ideally, the location, size and flow characteristics of each path should be known, although in practice, this is rarely possible and, instead, an approximation or amalgamation of paths is almost always necessary. The flow through each opening may usually be approximated by the Power Law equation:-

$$Q = k(\Delta p)^n \qquad (m^3/s) \qquad (1)$$

where Q = volumetric flow rate (m^3/s)
k = flow coefficient (m^3/s at 1 Pa)
n = flow exponent
Δp = pressure difference across opening (Pa)

The flow coefficient, k, is related, in part, to the size of opening, while the flow exponent, n, characterises the flow regime and has a value ranging from between 0.5 for fully turbulent flow to 1.0 for wholly laminar flow. In practice, the flow exponent often has a value for typical cracks and other openings in building structures of between 0.6 and 0.7.

The pressure differences driving air infiltration and ventilation are maintained by the climatic influence of wind and temperature and/or the operation of a mechanical ventilation system. The surface pressure due to wind is given by

$$p_w = \rho C_p V^2/2 \qquad (Pa) \qquad (2)$$

where ρ = air density (kg/m^3)
p_w = surface pressure due to wind (Pa)
C_p = pressure coefficient
V = mean wind velocity at a specified datum level (usually building height) (m/s)

The pressure coefficient, C_p, is normally assumed to be invariant to windspeed but is dependent on wind direction and on the spatial location on the building surface. Some representative values are given in the AIVC's Calculation Techniques Guide (1), however published data for typical buildings is sparse.

The pressure difference, resulting from stack action, between two vertically spaced openings, is given by

$$p_s = -\rho_o g h 273(1/T_{ext} - 1/T_{int}) \qquad (Pa) \qquad (3)$$

where ρ_o = air density at 273K and at ambient pressure (kg/m^3)
h = vertical distance between openings (m)
T_{ext} = external air temperature (K)
T_{int} = internal air temperature (k)

This quantifies the vertical pressure distribution between the inside and outside air masses due to density differences. In the numerical approach outlined it is sufficient to specify stack pressure with respect to any suitable datum level such as ground level or the height of the lowest opening.

The total external pressure acting on each opening is the sum of the stack and wind components. Thus for the i'th flow path, the total pressure ,p_i, is

$$p_i = p_{si}+p_{wi} \qquad (4$$

Assuming a total of j flow paths, then by substituting into equation(1), flow balance between the incoming infiltrating air and the displaced exfiltrating ai is given by

$$\sum^{j} [\ \underset{\text{infiltration}}{\overset{pi>pint}{k_i(\ p_i-p_{int})^{n_i}}} + \underset{\text{exfiltration}}{\overset{pi<pint}{k_i(p_{int}-p_i)^{n_i}}}] = 0 \qquad (5$$

This is a very simple and often a good approach to adopt since, in many instances, a "single zone" approximation provides a satisfactory approach while at the same time, there is only one numerical unknown to determine, which is th internal building pressure. Although a direct analytical solution to this equation is not normally possible, it is a simple matter to solve it iteratively, by successively revising the internal pressure value until a flow balance is acheived between the infiltrating and exfiltrating airflows. Normally a tolerance of +/- 0.0001 m^3/s in flow balance gives a satisfactory result. Furthermore, mechanical extract or supply ventilation can be accommodated by imposing a fixed flow condition in one of the paths to represen the ventilation rate, while balanced ventilation can be approximated by direct summation to the calculated infiltration rate. The consequent flow rates and pressure drops across the remaining paths are automatically calculated. Thus such conditions as unacceptable pressure values, backdraughting risks or climatic influences can be readily monitored, as can the flow rates through eac path and the direction of flow.

Where internal partitioning causes a signficant impedence to flow, then interna flow paths need also to be given (multi zone network). While the same principles of solution apply, an internal pressure for flow balance must be evaluated in each zone. This can considerably increase the complexity of calculation as well as impose severe requirements on both the detail and accuracy of input data.

The heat load necessary to compensate for the difference in temperature between the incoming fresh air and the required internal air temperature is:-

$$H = Q\rho c_p(T_{int}-T_{ext}) \ \ (W) \qquad (6$$

where H = heat load (W)
Q = flow rate of incoming air (m^3/s)
c_p = specific heat of air

In part, some preheating of the ingressing air may occur as it passes through the building fabric (Kohonen et al (2)) and some further gains may be received from incidental sources but, for the purposes of this exercise, no assumptions regarding the magnitude of these gains have been made.

INPUT DATA

The information required in order to predict air infiltration and ventilation can be broadly classed into building specific and weather specific data. Building data is very much fixed by the choice of design and includes such factors as its height, shape, flow path distribution and surrounding environment. Again an attempt has been made to categories the flow path characteristics of typical building elements (1) but in some instances direct measurements may be needed.

On the otherhand weather data is very variable and, although in part, is dependent on location, nevertheless has a considerable impact on the overall variabilty of air change and consequential heat loss. It is therefore essentia to establish a consistent method for the incorporation of weather data. The CIBSE Example Weather Year Data provides such a method. It is based on an hourly sequence of actual observations througout a 12 month period and is intended to represent the least abnormal year for which data are available. As such, it provides an ideal base for the hour by hour prediction of air infiltration and natural ventilation; it also enables an identical weather sequence to be used in the comparison of alternative design options.

In ventilation analysis, the weather data of principal concern are wind velocity, for the calculation of wind pressure, and air temperature for the calculation of stack pressure and heat loss. However, it is essential to consider the microclimate surrounding the building rather than the "remote" station from which the raw meteorological data are obtained. Also, since natural ventilation is driven by the combined effects of wind and temperature, it is necessary to combine the wind and temperature data into a matrix of time intervals over which given combinations of wind and temperature occur. This is illustrated for the Kew Example Weather Year Data in Table 1.

The strength of the wind is influenced by the roughness of the underlying terrain and by the height above ground level. Therefore, a correction to the measured windspeed needs to be made, to allow for the intervening terrain roughness between the measurement site and the building location, and to compensate for the difference in elevation above surface level between the datum height for the measurement of wind (10m) and the datum height for the wind pressure calculation (building height). This is covered in Part A2-31 of the CIBSE Guide (3) and in British Standard BS5925 (4), in which the windspeed at a specified height, z, is approximated by:-

$$V = V_m k_s z^a \quad (m/s) \qquad (7)$$

where V = reference height windspeed (m/s)
V_m= 10m met station windspeed (m/s)
k_s and a = terrain roughness coefficients

Typical values of the terrain roughness coefficients, k_s and a, taken from BS5925 (4), are reproduced in Table 2. The product "$k_s z^a$" of Equation (7) is best considered as a "wind reduction factor", by which the meteorological site windspeed is multiplied in order to obtain the roof height value.

TABLE 1 - CIBSE Example Weather Year Data for Kew Gardens showing Frequency Distribution of Hourly Wind and Temperature.

Temperature Range (deg C)	Wind Speed Range (m/s)												
	.0 to 1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 13.0
-8.0 to -6.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
-6.0 to -4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
-4.0 to -2.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
-2.0 to .0	.2	.1	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0
.0 to 2.0	.3	.3	.3	.2	.1	.1	.2	.1	.1	.1	.0	.0	.0
2.0 to 4.0	.3	.5	1.3	1.1	.6	.5	.6	.5	.3	.1	.1	.0	.0
4.0 to 6.0	.4	.6	1.2	1.7	1.1	.9	.6	.5	.3	.1	.0	.0	.0
6.0 to 8.0	.7	.7	1.6	2.1	1.9	1.6	.7	.4	.2	.1	.1	.0	.0
8.0 to 10.0	1.2	.6	1.2	1.7	1.5	1.5	1.0	.7	.3	.1	.1	.1	.0
10.0 to 12.0	1.4	1.3	1.9	2.0	1.9	1.6	1.1	.7	.4	.3	.1	.0	.0
12.0 to 14.0	.9	1.1	2.4	2.1	1.7	1.6	1.2	.8	.5	.2	.2	.0	.0
14.0 to 16.0	.9	1.2	2.3	2.3	2.0	1.8	1.0	.7	.4	.2	.1	.1	.1
16.0 to 18.0	.8	.8	1.7	1.9	1.8	1.5	1.0	.5	.3	.1	.1	.1	.1
18.0 to 20.0	.4	.5	.9	1.3	1.4	1.5	.9	.6	.1	.1	.0	.0	.0
20.0 to 22.0	.2	.3	.5	.8	.7	.6	.5	.2	.1	.1	.0	.0	.0
22.0 to 24.0	.0	.1	.3	.5	.4	.3	.2	.2	.0	.0	.0	.0	.0
24.0 to 26.0	.0	.1	.2	.2	.1	.2	.1	.0	.0	.0	.0	.0	.0
26.0 to 28.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
28.0 to 30.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30.0 to 32.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Total percentage in frequency distribution table is 100.0%

TABLE 2 - Terrain Coefficients (reference 4).

Terrain	k_s	a
Open flat Country	0.68	0.17
Country with scattered wind breaks	0.52	0.20
Urban	0.35	0.25
City	0.21	0.33

Therefore, to predict the ventilation rate and resultant heat loss, using the CIBSE Example Weather Year Data, it is first necessary to tabulate the data in the form of wind/temperature sequences. The wind speed for each of the sequences or combinations is corrected for building height and terrain conditions and the corresponding wind induced surface pressure is calculated for each flow path. The stack pressure is similarly evaluated for each path and combined with the wind pressure to obtain a total pressure, p_i. The resultant air change rate and ventilation heat loss may be evaluated for each of the data combinations by solving equations (5) and (6) respectively.

EXAMPLES

Ventilation and Heat Loss calculations

Figure 1 depicts a single zone leaky enclosure with a volume of approximately 1000m^3. For simplicity of presentation a 2-dimensional section is presented, although there is no inherent calculation difficulty in considering a 3-dimensional network. The structure has a total height above ground of 6m and is assumed to be located in an urban area with surrounding buildings of similar height. Using the CIBSE Weather Year Data presented in Table 1, the distribution in infiltration rates and the ventilation heat load for external air temperatures of 15^{0}C and below are calculated. The flow path data are summarised in Table 3, where the leakage coefficients are based on values assumed to be typical for a warehouse type building. A uniform distribution of wall leakage is assumed, represented by flow paths in each wall at a height above ground of 1.25m and 3.75m (ie 0.25 and 0.75 of wall height). Similarly, adventitious roof leakage is represented by flow paths in each section at 5.5m above surface level. The wind pressure coefficients were taken from Table 6.2.3 of the AIVC Calculation Techniques Guide (1) and the wind reduction factor of 0.55 was derived from k_s and a values of 0.35 and 0.25 respectively (Table 2, urban terrain). An internal air temperature of 20^{0}C was assumed, while the external air temperatures were taken directly from the CIBSE Weather Year Data.

TABLE 3 - Summary of Flow Path Data

Path No.	Height (m)	k (m^3/s at 1 Pa)	n	C_p
1	1.25	0.08	0.6	0.2
2	3.75	0.08	0.6	0.2
3	5.5	0.10	0.6	-0.3
4	1.25	0.08	0.6	-0.25
5	3.75	0.08	0.6	-0.25
6	5.5	0.10	0.6	-0.3

wind reduction factor = 0.55 (see text)

Results. A scatter plot of infiltration rates for each combination of wind and temperature is presented in Figure 2. This represents the "infiltration characteristics" of the building and clearly depicts the temperature or stack dependent regime, where wind speed has only a marginal effect on flow rates, followed by the wind dependent regime, in which temperature effect become marginal. Also illustrated in Figure 2 is the wide variation in flow rate according to weather conditions. The infiltration characteristics are unique to each building and are dependent on leakage parameters, shielding and orientation. The relative importance of the wind and stack regimes depend on such factors as the vertical distribution of openings and on the presence of wind shelter. For the set of conditions considered in this example, the minimum infiltration rate is $0.11m^3/s$, whereas the maximum value is $0.8m^3/s$, giving a variation in values of approximately 7:1. The average value of infiltration rate is $0.39m^3/s$. By applying equation (6), the corresponding heat load figures are a minimum of 0.7kW, a maximum of 14.4kW and a mean of 5.9kW. Thus the variation in heat load from minimum to maximum is in the ratio of almost 21:1

Although the infiltration characteristics provide a useful insight into the variability of climatically driven ventilation, they do not indicate the duration for which extreme conditions apply and are therefore of limited value in assessing heat load and air quality needs. Fortunately, the weather year data provides the required duration information, in the form of percentage time for which each combination of wind and temperature occurs. A frequency plot illustrating the duration of infiltration rates is illustrated in Figure 3. Although the variation in ratio of infiltration rates is 7:1 this plot shows that for 95% of this period, the ratio is 4:1. The corresponding heat load pattern is reproduced in Figure 4 and displays similar characteristics to the infiltration distribution. However, in reality there is only weak coupling between these two sets of data, as shown in Figure 5, in which the heat load is plotted against infiltration rate. The maximum heat load of 14.4kW occurs at an infiltration rate of $0.6m^3/s$, while the maximum infiltration rate of $0.8m^3/s$ gives a resultant heat load of only 4.9kW. There is also considerable scatter throughout intermediate points. Thus, from the viewpoint of sizing heating plant, it may often be that a moderately high air change rate will only be of secondary concern because it is not associated with low outside temperatures. This, in part, is recognised by the use of the "Infiltration" or "Wind Temperature" Number (Jackman (5)), which is defined as the multiple of windspeed and internal/external temperature difference. Its purpose is to determine a "peak" set of climatic conditions for design purposes, which allows for the possibilty that light winds with a low outdoor temperature may impose a thermal load equal to a strong wind at a moderate outdoor temperature. If there is a reasonable balance between the fabric heat loss and the infiltration heat loss, then Jackman (5) shows that the climatic conditions of wind and temperature corresponding to the maximum infiltration number also corresponds to the maximum heat loss from the building. A plot of infiltration number vs heat load is presented in Figure 6. While complete correlation cannot be expected, it may be seen that the maximum heat load coincides with the maximum "Infiltration Number". This corresponds to an external temperature of 1^0C and a building height windspeed of 5.23 m/s. Alternatively it is possible to correlate external temperature against heat load as illustrated in Figure 7. Again there is considerable scatter in results but the maximum heat load corresponds to an external temperature of 1^0C. These ideas could be further developed by considering an extreme weather sequence in which the adequacy of a heating system is analysed over a prolonged period of severe weather.

Airflow Distribution

In addition to considering the effect of climate on overall air change rate, it may be of significant importance to consider the pattern of flow in and out of the building. This is of special significance when investigating such factors as the backdraughting of flues or the flow of air from contaminated zones to other parts of the building. Figure 8 illustrates a flow network, similar to the previous example, in which the total air change rate remains constant but the airflow pattern varies. Under total stack flow (Figure 8a), flow enters through the lower openings and exfiltrates through the upper openings. However, as the wind increases, the infiltration rate remains substantially constant but flow reversal takes place, with air entering through both of the windward openings (Figure 8b). Eventually, the wind effect dominates, with wind entering through the windward face and exfiltrating through the leeward side (Figure 8c). Clearly, the wind direction can therefore also be an important parameter, in which case the statistical data of Table 1 must be presented for each sector of wind direction. This is perfectly possible but if the flow pattern takes on significant importance, then consideration might need to be given to the orientation of openings with respect to prevailing winds or to the implementation of mechanical ventilation.

CONTROLLING THE INFLUENCE OF CLIMATE

The most positive way to control the influence of climate is to construct airtight buildings and to provide ventilation by artificial means. This has become common practice in much of Scandinavia, with airtightness requirements being a feature of Building Regulations in both Sweden and Norway (Thompson(6)). Depending on the type of ventilation system, a certain degree of residual porosity is required, especially when make up air is not mechanically supplied. This is important in order to avoid excessive under pressures, sufficient to cause high velocity draughts or backdraughting. The weather data and calculation technique outlined in this paper can be readily applied to this problem. As an example, Figure 9a illustrates the typical air change characteristics of a "leaky" enclosure, in which a nominal 0.5 ach mechanical extract ventilation rate is applied. The actual air change rate is considerably influenced by climate, with the result that its energy and possibly comfort efficiency is poor. By tightening the building, Figure 9b, the rate of air change becomes almost invariant to climatic conditions.

Sometimes it is advantageous to eccentuate the effects of wind or stack action. This is very much a question of climatic location. In cold climates, where a consistent temperature difference between the inside and outside of the building is assured, the use of purpose provided stacks to promote stack ventilation is sometimes used. Guidelines for the use of passive ventilation stacks are included in current Swedish Building Codes (7) and in recent French Building Regulations (8). This technique is also gaining in popularity in the United Kingdom (Edwards and Irwin (9), Gaze (10)). Since the purpose of stack ventilation is to take advantage of temperature difference as the driving force, the use of shelter belts to minimise the influence of wind may also be desirable. On the otherhand, in regions where wind provides a reliable driving force, then designing for wind driven natural ventilation becomes important (Ashley (11)). Again with suitable weather data, alternative solutions can be analysed

CONCLUSIONS

The CIBSE Example Weather Year Data enables an hourly sequence of observed data to be used to estimate typical infiltration rate and resultant heating loads in buildings. The data also enables the distribution and duration of infiltration rates to be predicted, with the result that it is possible to predict peak heating loads and to identify possible air quality and comfort difficulties due to either insufficient or excessive air change rates.

While it is impossible to anticipate all the potential uses of the Weather Year Data, examples of its application, using a simple multi-flow-path, single-zone infiltration model, demonstrates the ease with which these data may be applied to a whole range of ventilation problems. The data may also be used to quantify the direction and rate of flow through openings in the building envelope. This could have important applications in the design and orientation of buildings for optimum ventilation performance. Additionally, the combination of climatic data with information on the magnitude and distribution of leakage openings, enables the performance of both purpose provided natural and mechanical ventilation systems to be assessed.

Whereas the Example Weather Year Data represents the least abnormal year for which data is available, the addition of severe weather sequence data would enable improved evaluation of the performance of heating systems under conditions of prolonged periods of poor weather.

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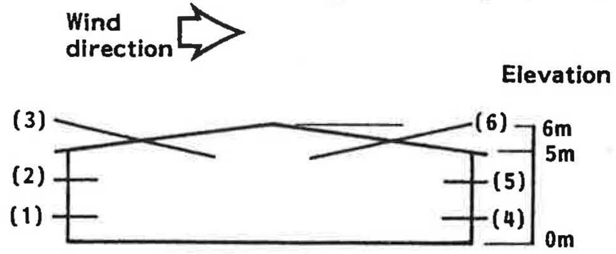

Bracketed numbers indicate flow paths

Figure 1. Single zone flow network

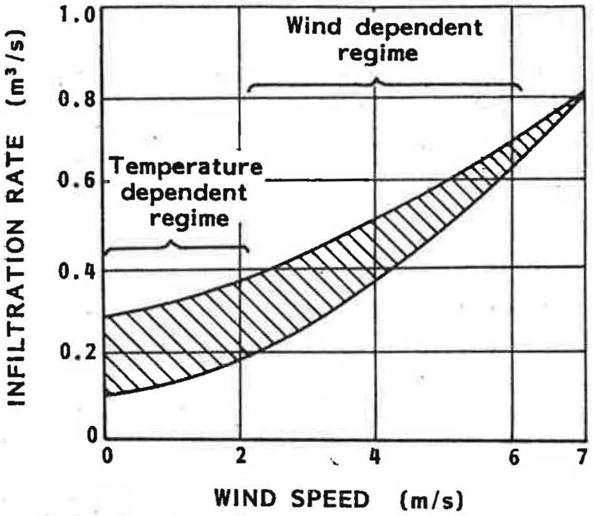

Figure 2. Infiltration characteristics

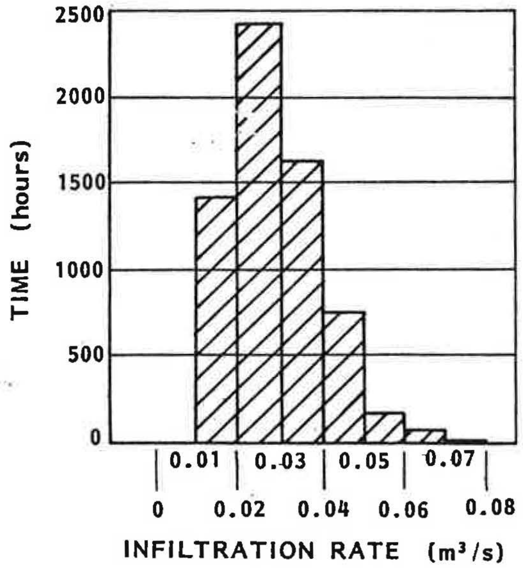

Figure 3. Infiltration distribution

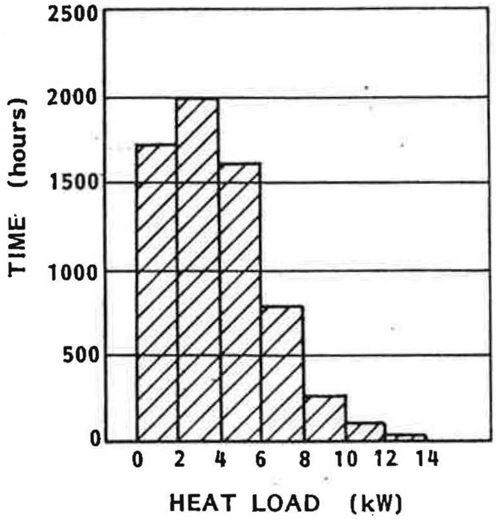

Figure 4. Heat load distribution

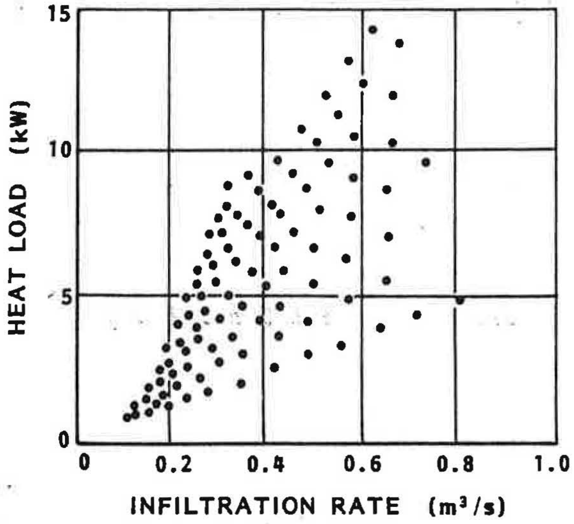

Figure 5. Infiltration vs heat load

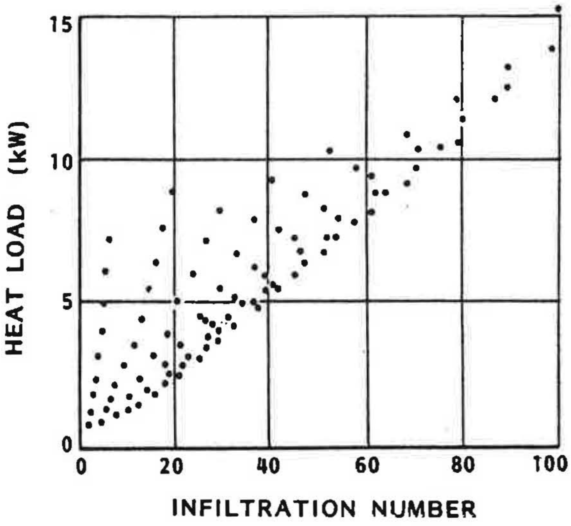

Figure 6. Infiltration No. vs heat load

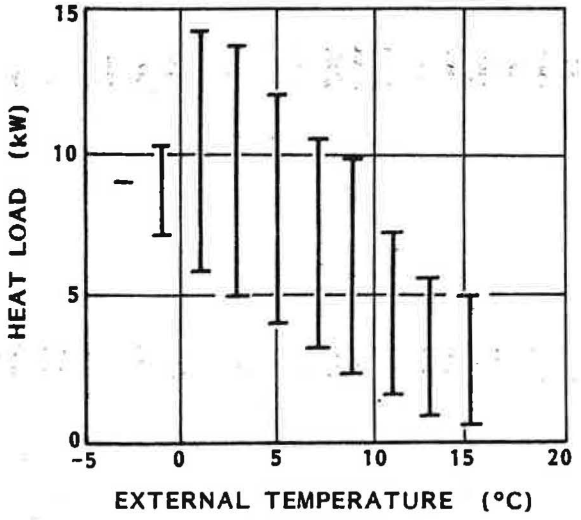

Figure 7. External temperature vs heat load

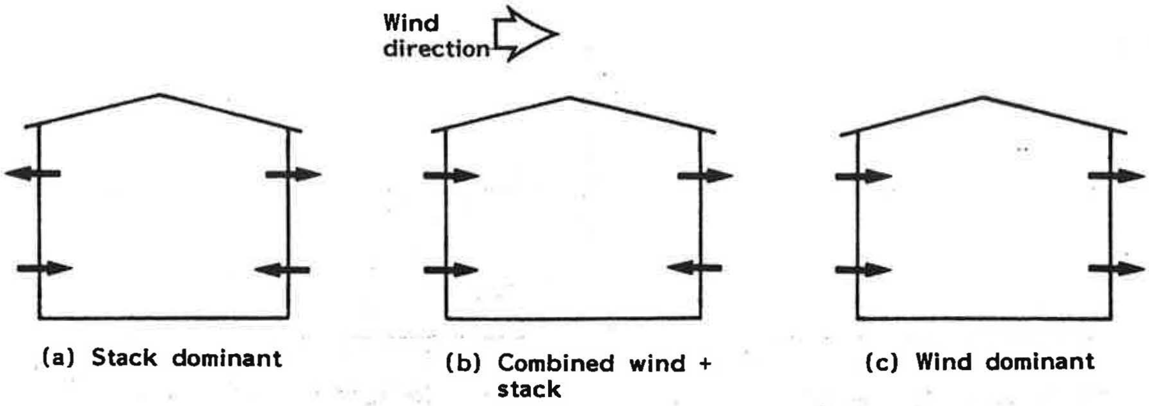

Figure 8. Airflow distribution patterns for constant airchange

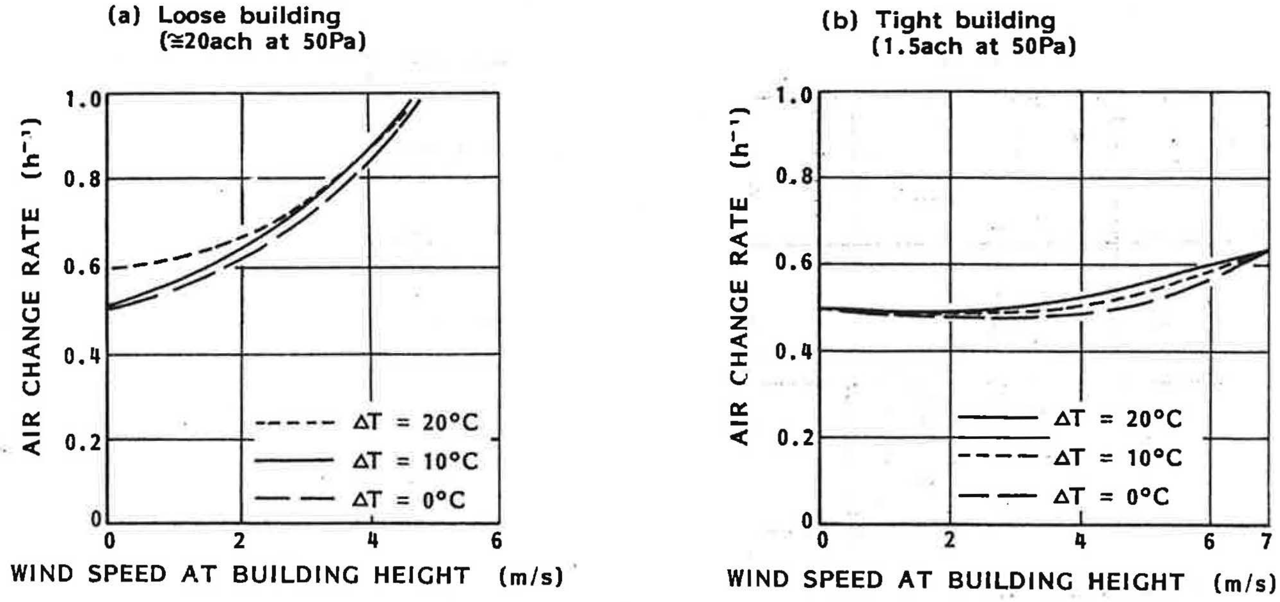

Figure 9. Combined influence of mechanical extract ventilation at 0.5ach and climate on airchange rate