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Controlled Background Ventilation for Large Commercial Buildings

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SUMMARY

The basis of good design for ventilation provision is to make the building envelope airtight and then to provide controlled ventilation; i.e. the concept of 'build tight - ventilate right'. This approach reflects and addresses current concerns regarding indoor air quality, energy conservation and associated environmental issues. In naturally ventilated buildings, a tight envelope (effective in limiting uncontrolled infiltration through the building fabric) requires the provision of adequate and controlled background ventilation to meet the health requirements of the occupants.

A preliminary study was carried out on a three-storey naturally ventilated office built as a low-energy building. The study uses a multi-zoned prediction programme to determine various ventilation strategies to provide controlled background ventilation. Full-scale, whole-building pressurisation measurements are used to provide envelope leakage characteristics. The surface wind pressure coefficient data is provided through measurements carried out in the Building Research Establishment's Environmental Wind Tunnel.

This study assessed the effectiveness of permanent but controllable background ventilators in naturally ventilated, office-type buildings with different envelope tightness. It was shown that, during the heating season, it is possible to provide adequate background ventilation for occupant comfort by incorporating commercially-viable, manually-controllable trickle ventilators within each room. Recommendations for possible consideration may be that 4,000 mm^2 open-area ventilators could be used in rooms with floor areas less than 10 m^2 and 400 mm^2 per m^2 (of floor areas) for those which are larger.

1. INTRODUCTION

This paper reports a preliminary study carried out to determine whether permanent and controllable ventilators (e.g. 'trickle' ventilators) could provide adequate background ventilation for occupants in naturally-ventilated office buildings. The aim would be to satisfy fresh air requirements for metabolic needs and to control body odour. Provision for 'rapid' ventilation to address issues of summer over-heating or tobacco smoking would need to be addressed by other means such as openable windows and will be the subject of a separate study.

The underlying philosophy behind this paper is the concept of 'build tight - ventilate right'. While adequate ventilation is essential for the health, safety and comfort of building occupants, excessive ventilation leads to energy waste and sometimes to discomfort. Adventitious leakage of air (infiltration) through cracks and gaps in the building fabric is not designed for nor is it controllable by the occupants and can therefore be considered both as an overhead and a penalty. The basis of good design is to make the building envelope airtight and to provide controlled ventilation as and when it is needed.

When considering adequacy of ventilation, it is more relevant to discuss the ventilation 'performance' of the building rather than its ventilation characteristics, i.e. to determine how often adequate ventilation would be obtained during the appropriate occupation period rather than how the ventilation rate varies with weather conditions such as wind speed, direction and air temperature. The section 'prediction setup' below not only describes the building and the data (both model- and full-scale) necessary for the predictions but also the meterological 'frequency' data relevant to the building site.

This preliminary study is carried out on an example three-storey naturally ventilated office building. Ventilators with either of two commercially-realisable 'open' areas are considered so that guidance can be provided on how they would function in an office building. The effectiveness of these ventilators when incorporated in external walls with differing envelope airtightness is also considered.

2. PREDICTION SETUP

2.1. Building

The building chosen for the study was the BRE low-energy office (LEO). This proved useful in three respects; its form and size were similar to many medium-sized naturally-ventilated buildings found in the UK, model-scale wind pressure coefficient data on this building were available for prediction purposes and, full-scale measured data on the ventilation rates of the building were available for evaluating the prediction procedure.

Figure 1 shows the three-storey LEO building which is rectangular (60 m x 12 m) in plan and with floor-to-ceiling heights of 2.6 m in each storey. Offices are located on each floor along either side of a central corridor running along an east-west axis. The north-facing facade contains the main entrance to the building. The estimated total volume of the building is 5430 m^3 and the surface area is 1930 m^2. Although the building has a mechanical ventilation system, occupants are free to open the windows whenever they choose. There are no trickle-ventilators anywhere in the building. More details of the building can be found in Reference 1.

2.2. BREEZE Prediction Programme

BREEZE is a suite of integrated and user-interactive computer programs [2] developed at BRE to evaluate ventilation rates and interzonal airflows in multi-storey, multi-celled buildings. The building is taken to consist of a number of interconnected zones, each at a specific pressure, with air moving from regions of high to low pressures.

The pressure differentials are set up both by the action of wind on the external surface of the building and by the temperature difference between air inside and outside. The amount of air flowing between the outside and various zones, or between the zones themselves, is governed by the magnitude of pressure differentials and by the type of flow path (such as open doors and windows). The analysis procedure applies methods of network flow computation and uses mass balance to solve for an interior static pressure within the building by requiring that the inflows and outflows for each zone balance to zero.

To account for infiltration through the external envelope, the programme incorporates an algorithm [3] and a unique implementing method for multi-celled buildings. Background leakage is, therefore, not modelled as discrete cracks with some pre-judgement being necessary as to their size and location. BREEZE now models this as distributed leakage over the whole of the permeable envelope.

2.3. Wind Pressure Coefficients

Surface wind pressure coefficients for use in the prediction procedure were obtained by carrying out wind-tunnel measurements on a 1:200 model of the LEO building. The pressure-tapped model together with nearby buildings were mounted on a 1.75 m diameter turntable in the BRE Environmental Wind Tunnel. Measurements were carried out with a simulation of the approaching wind corresponding to that over a suburban terrain at a scale of 1:200. Fuller details of the simulation are given in Reference [4].

All pressures were measured using pressure transducers and scani-valve systems under on-line computer control. Details of the system and data-acquisition procedure can be found elsewhere [5]. The pressure coefficients at each building-facade location for each of the 12 principal wind directions were obtained by normalising the measured pressure by the reference dynamic pressure. This reference was measured at roof-height of the building and well upstream of the model.

2.4. Building Envelope Air Leakiness

Whole-building envelope leakage measurements of office buildings have been carried out previously [6] using a large-building fan 'pressurisation' rig known as BREFAN [7]. These measurements indicated that it is possible to categorise the tightness of buildings by measuring the air leakage rate at an imposed pressure differential of (say) 25 Pa between inside and outside. At this pressure difference, measurements in UK offices indicated that values of 5, 10 and 20 m^3/h per m^2 of envelope area would correspond respectively to buildings which could be classified either as 'tight', 'average' or 'leaky'.

For use within the prediction programme, the above values were translated to the form of the power-law equation [7]

$$Q = k(\Delta p)^n$$

where Q is the airflow rate at a pressure differential Δp across the building envelope (here set at 25 Pa), k is a constant and n is an exponent lying between 0.5 and 1.0. Using results obtained previously for the LEO building, n was kept at a constant value of 0.6 for the present study and the value of k varied to simulate different envelope airtightnesses.

2.5. Meteorological Data

For the purposes of this study, it seems appropriate to use meteorological data for a suburban site (rather than a city centre) since it would not be unusual to site a naturally-ventilated building in such a location. Garston, where the BRE low-energy office is located, although somewhat rural has surroundings typical of a suburban site.

A measure of the climatic conditions at Garston was obtained by considering data obtained over a 10-year period at the nearby meteorological station at Heathrow. To account for change of terrain, wind speeds at the site were reduced to 62% of that recorded at Heathrow following a standard calculation procedure [8].

The data obtained were constrained to the winter heating season, i.e. beginning of October to end of March and to the time period between 0900 to 1800 when the building would normally be occupied. No attempt was made to segregate the weather data further to exclude weekends since the standard occupancy pattern of a full week is used to calculate energy demands in offices [9].

Figures 2 to 4 show the weather conditions expected at the site for this restricted period. Winds from the south-west predominate. The mean wind speed and the outside air temperature exceeded for 50% of the time are about 2.4 m/s and 9.3°C respectively.

2.6. Characteristics of Trickle Ventilators

Current guidance [10] for housing says that requirement for background ventilation of a habitable room will be satisfied if it has a ventilation opening (or openings) not less than 4000 mm^2, e.g. a trickle ventilator. For this study, effectiveness of trickle ventilators of this size were considered by incorporating them into each of the cellular offices.

However, it is recognised that office rooms vary in floor size and therefore, it would be appropriate to consider an alternative strategy of incorporating trickle-ventilators with an open area of 400 mm^2 per m^2 floor area. The relationship between volume airflow rate, Q, and pressure difference Δp for these devices were taken to be [11],

$$Q = AC_d\sqrt{\frac{2\Delta p}{\rho}}$$

where A is the area of the opening, C_d is a constant (= 0.61) known as the discharge coefficient and ρ is the density of air passing through the opening.

3. PREDICTION PROCEDURE

3.1. Validating Prediction Versus Measured

Using sulphur hexafluoride as a tracer gas, whole building infiltration rate measurements have been previously carried out [12] in the LEO building. An infiltration rate of 0.18 airchanges per hour (ach) was measured with all windows and doors closed when the wind blowing from 210°N (the prevailing wind direction) was measured as between 3.3 and 4.1 m/s on a nearby 10 m high weather mast. During the test, all windows and external doors were kept closed but all internal doors were kept open to allow the tracer gas to disperse within the building.

Prediction carried out for a wind of 4.1 m/s from the same prevailing direction with inside and outside air temperatures of 18.8 and 7.3°C respectively gave a predicted infiltration rate of 0.17 ach giving some confidence to the prediction procedure. Although not mentioned here for the sake of brevity, further predictions were carried out for variations in wind speed, wind direction and inside/outside temperature difference. The results were systematically assessed to ensure the integrity and validity of the modelling procedure.

3.2. Effect of Wind Direction

Figure 5 shows an example of the variation of the infiltration rate with wind direction with and without the (400 mm^2 per m^2) trickle-ventilators. For this example, the building envelope is 'tight', wind speed is set at 4.1 m/s and the inside/outside temperature difference is maintained 11.5°C.

Figure 5 shows that trickle-ventilators, in this instance, can approximately triple the airchange rate of the building by adding a controllable ventilation component to the uncontrollable background infiltration. As expected, maximum rates occur when the wind is normal to the two long faces of the building. However, complete symmetry in the airchange rates (e.g. those for northerly and southerly winds) is not obtained because the measured pressure coefficients reflect the proximity effect of adjacent buildings. In particular, as a result of an adjacent building 'butting' onto the LEO building on its north facade near the north-east corner.

3.3. Variation with Wind Speed and Air Temperature

Figure 6 shows the variation of the whole-building airchange rate, with and without trickle-ventilators, for northerly winds and over a wide range of wind speeds. The effect of the inside/outside temperature difference is also shown by keeping the internal temperature fixed at 18.5°C and varying the external air temperature.

As expected for a low-rise building, temperature-induced buoyancy flows do not dominate. The building airchange rate, therefore, does not vary significantly with outside air temperature but only (approximately linearly) with wind speed.

3.4. Ventilation Performance

These ventilation predictions, although specific to the building, make no reference to the local climatic conditions at the site. To assess the ventilation performance and to predict how often various levels of ventilation could be expected, the predicted ventilation characteristics have to be combined with the weather frequency distribution, i.e. the concurrence of wind direction, wind speed, and outside air temperature during occupancy.

The design or required inside air temperature was taken as 18.5°C, the value used for the LEO building [12]. The airchange rates were determined for a combination of wind speed and outside air temperature. Winds from only two directions (0° and 270°N) were considered to reduce the number of prediction runs required,

These two directions were respectively chosen to give the maximum and minimum boundaries of the expected performance envelope. In each of these simulations, it was assumed that these winds would be blowing for the full period under consideration. The 270° rather than the 240°N direction was chosen since it was considered that the latter, because of the nearby building, had attenuated (Fig. 5) the expected airchange rate.

Figure 7 shows the ventilation performance envelope for the building with a tight envelope and without any ventilators. To provide an estimate of the expected 'average' performance, further analysis was carried out by considering the other wind directions as either a 'maximum' or 'minimum'. In this way, all winds from sectors (inclusive) 330° to 30°N and 150° to 210°N were expected to give maximum airchange rates while minimum rates would be expected from sectors 60° to 120°N and 240° to 300°N. Figure 7 shows the expected average ventilation performance derived by this method.

4. VENTILATION PERFORMANCE

4.1. Effect of Envelope Airtightness

Figure 8 shows the effect that envelope airtightness has on the predicted infiltration performance of the office building. As expected, it can be seen that the leakier the building is, the greater is the uncontrolled infiltration rate at any frequency of occurrence. The mean (50% occurrence) infiltration rate expected over the heating season (and during occupied hours) shows this increase as,

'tight' envelope	0.12 ach
'average' envelope	0.23 ach
'leaky' envelope	0.38 ach

This shows that a leaky building can triple the infiltration rate found in a similar building with a much tighter envelope. Not only does the mean rate increase but also the range, i.e. 'spread', of expected infiltration rates. This can be seen by considering the differences between the 10 and 90% rates shown in Figure 8.

4.2. Effect of Ventilators

When trickle ventilators are incorporated into the building fabric (so that each office room has one), additional but controllable ventilation increases the expected airchange rates within the office building (Figure 9). The mean (50% occurrence) airchange rates obtained from the predictions are as follows,

	No Vents	**Ventilators (4000 mm^2) in each room**	**Ventilators (400 mm^2 per m^2 of floor area) in each room**
	Uncontrollable infiltration rate (ach)	*Additional & controllable ventilation (ach)*	*Additional & controllable ventilation (ach)*
'tight' building	0.12	0.16	0.24
'average' building	0.23	0.15	0.25
'leaky' building	0.38	0.18	0.27

In general, floor areas of individual rooms are more than 10 m^2 in this building. As a result, the above table shows that the strategy of incorporating 400 mm^2 per m^2 (of floor area) ventilators in each room gave a higher controllable ventilation rate than with fixed ventilators set at 4000 mm^2 per room.

It should be noted that the mean infiltration rate of the leaky building is similar to that obtained with controlled ventilation in the 'tight' building. Therefore, while occupants in a 'tight' building have the opportunity to reduce ventilation rates using controlled ventilators, no such opportunity is available for occupants in leaky buildings.

4.3. Comparison with Required Ventilation Rates

In the UK, CIBSE [13] recommends for offices a fresh air rate of 8 l/s per person. The minimum rate allowable is given as 5 l/s per person while 16 l/s per person is recommended when there is some tobacco smoking. According to CIBSE, occupants are usually insensitive to changes in ventilation over this range.

A medium-sized building like the LEO building can comfortably accommodate about 70 occupants. The required ventilation rate for this building is then estimated to be 0.37 ach with a minimum of 0.23 ach and a possible upper rate of 0.74 ach.

Comparing (Figure 9) these rates with those predicted above for the buildings with different envelope airtightness, it can be seen that the uncontrolled infiltration rate for the tight building is below the required minimum value. Therefore, a tight building may not necessarily satisfy occupants' minimum ventilation requirements solely by infiltration but will require the provision of additional and appropriate controllable background ventilation. The results given here show that, with 400 mm^2 per m^2 ventilators, it is possible to provide this controlled intake of fresh outside air to satisfy both minimum and recommended rates.

For the 'average' building, it appears that infiltration alone would be able to satisfy minimum requirements while the use of trickle ventilators should provide a controllable means to satisfy the recommended rate. In this instance, control over the required ventilation can still be obtained with trickle ventilators.

However, this does not appear to be the case with a 'leaky' building. Results indicate that infiltration through the 'leaky' building covers both the minimum requirements and that recommended. While it is possible to consider this admirable, it also means that occupants have no means of reducing these rates if and when they consider them excessive.

5. SPACE HEATING REQUIREMENTS

During the heating season, both air infiltration and provision of controlled ventilation imposes a demand on the space heating requirement for the building. To identify the extent of this demand, a standard CIBSE design procedure [9] was used. Appendix 1 contains the data used in the calculations. Figure 10 shows the resulting total heating requirements as split between fabric and ventilation losses.

It can be seen that fabric losses from the building remains relatively constant between 430 to 460 GJ over the heating season. However, losses due to ventilation vary considerably depending on the airtightness of the building and whether or not ventilators are used. In the absence of ventilators, Figure 10 shows that infiltration accounts for about 70 GJ in the tight building. This trebles to about 220 GJ when the building envelope is leaky accounting for nearly one-third of the total space heating demand.

As expected, incorporating trickle ventilators in the building increases the ventilation heat losses. As an example, losses increase from 70 to 210 GJ for the tight envelope and from 220 to 380 GJ for the leaky building. However, all these increases are under the direct control of the occupants who determine whether or not they should open the ventilators.

6. DISCUSSION AND CONCLUSIONS

This preliminary study was carried out to determine whether, in the heating season, controllable ventilators, such as trickle ventilators, could provide adequate background ventilation in multi-celled office buildings. Using a prediction procedure, their effectiveness was assessed in a medium-sized office building. As part of this assessment, the airtightness of the building envelope was also considered.

As expected, it was found that the average infiltration though a 'tight' building was only about a third of that found in a 'leaky' building. Furthermore, the tighter the building, the greater the reduction in the range or 'spread' of uncontrolled infiltration rates during the heating season. The energy consequence of a leaky building was also assessed. It was shown that infiltration in the leaky building accounted for nearly one-third of the total space heating demand compared to one-seventh in the tight building.

It was shown that background ventilation required for occupant comfort can be provided in 'tight' buildings by incorporating trickle-ventilators in each room. If the devices are of the 'hit-and-miss' variety and can be manually controlled, as is now common practice in dwellings, then the occupants have the freedom to control the amount of fresh outside air they feel they need. A recent study [14] has shown no evidence of cold draughts from trickle ventilators when mounted in window frames.

It may seem somewhat perverse to advocate the construction of a building with a tight envelope and to then make it leakier by incorporating trickle ventilators. But what is important is that a tight envelope minimises uncontrolled infiltration, i.e. ventilation that is not designed for, and reduces possible discomfort to occupants, say for example, through cold draughts at ankle-level. On the other hand, trickle-ventilators can provide, in a controllable manner, adequate background ventilation to satisfy recommended rates.

In conclusion, this study has shown that it is possible to provide adequate background ventilation in multi-celled office buildings by incorporating commercially viable, manually-controllable trickle ventilators within each room. Recommendations for possible consideration may be that 4,000 mm^2 open-area ventilators could be used in rooms with floor areas less than 10 m^2 and 400 mm^2 per m^2 (of floor area) for those which are larger.

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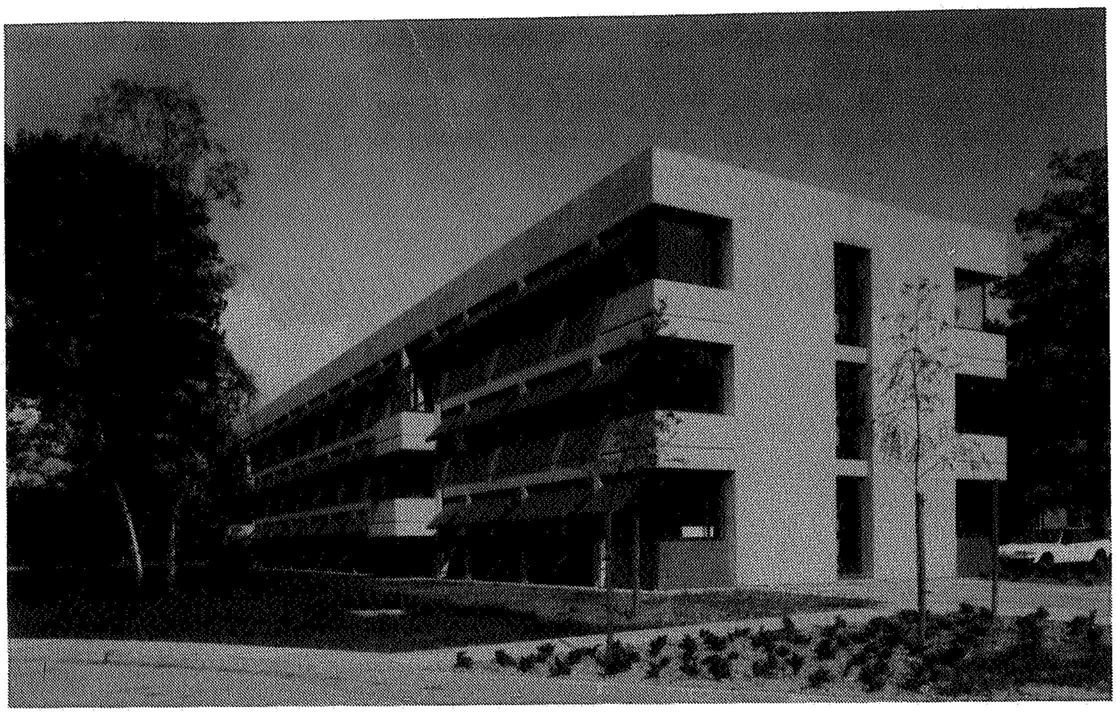

Figure 1. View of LEO building from south-east

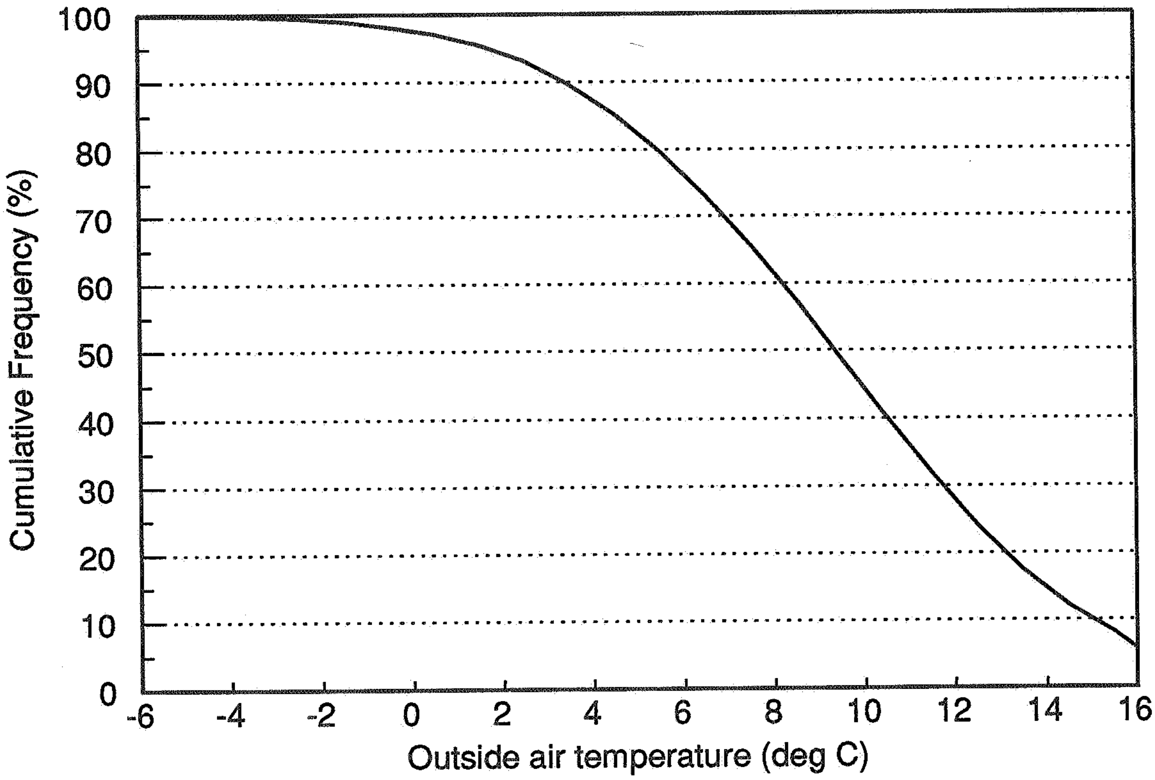

Figure 2. Outside air temperature at meteorological station

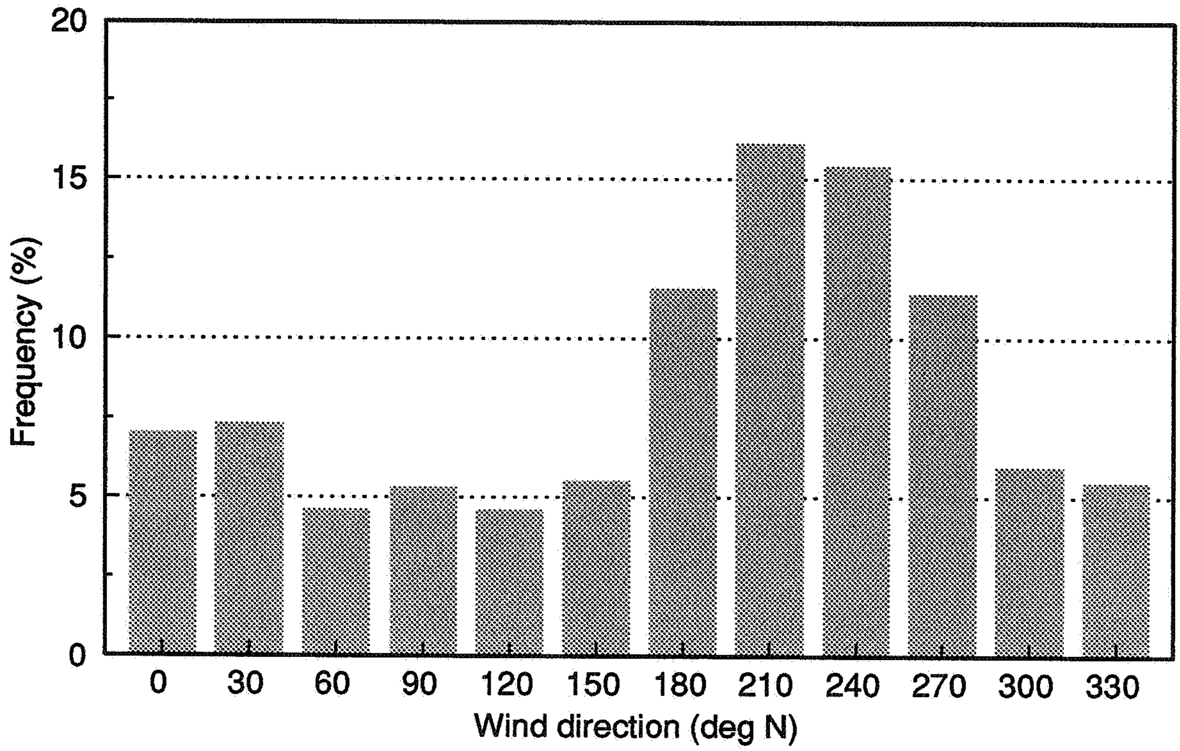

Figure 3. Wind direction at meteorological station

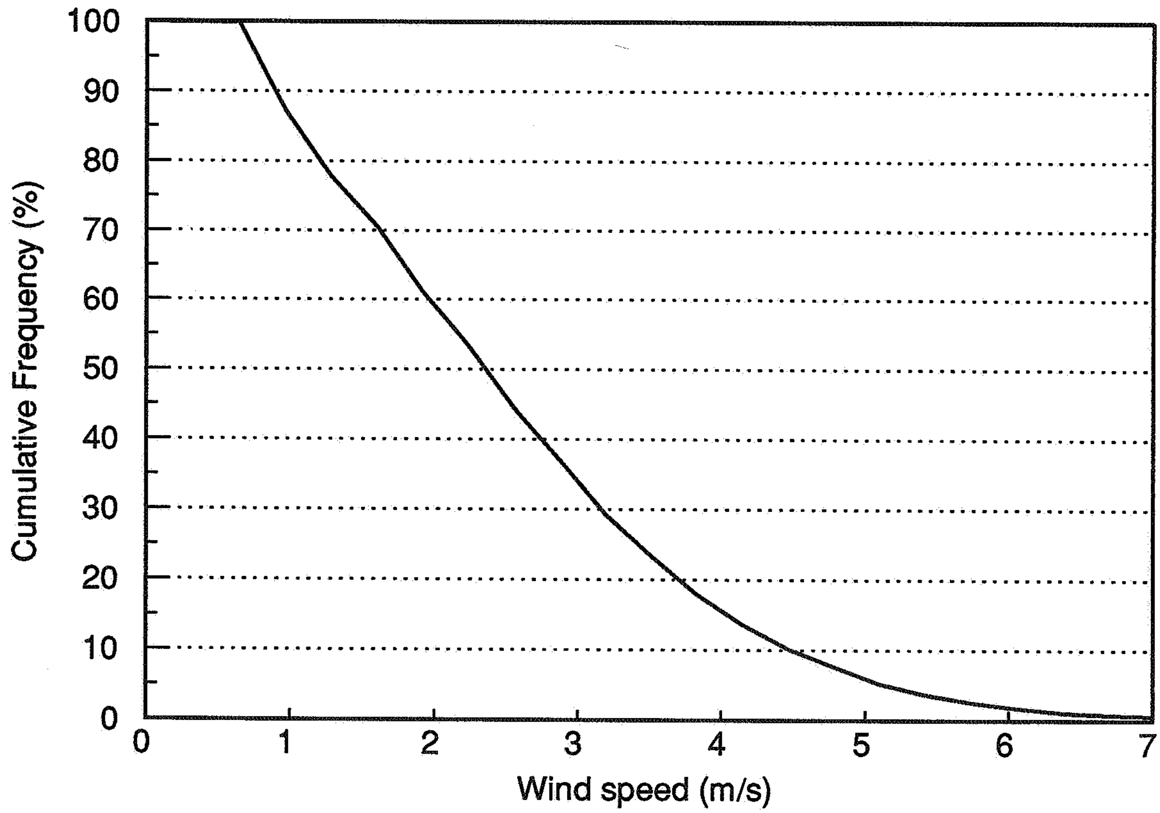

Figure 4. Wind speed at Garston

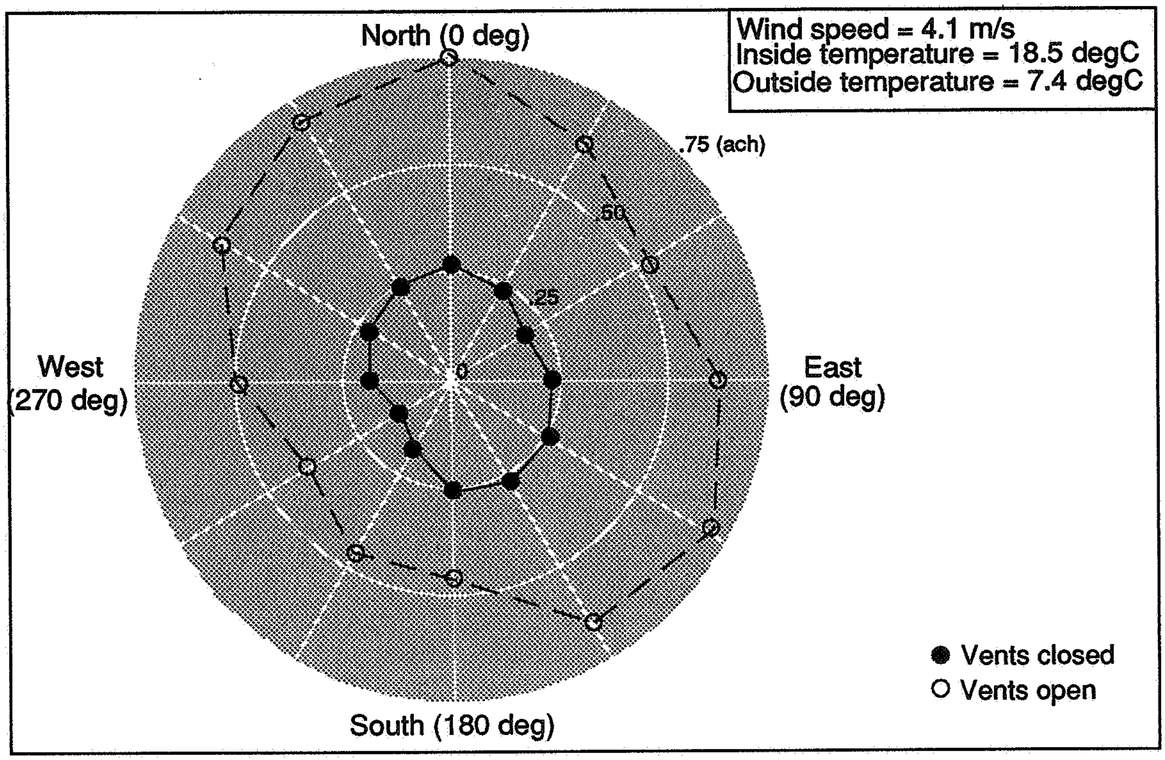

Figure 5. Effect of wind direction on airchange rates (ach)

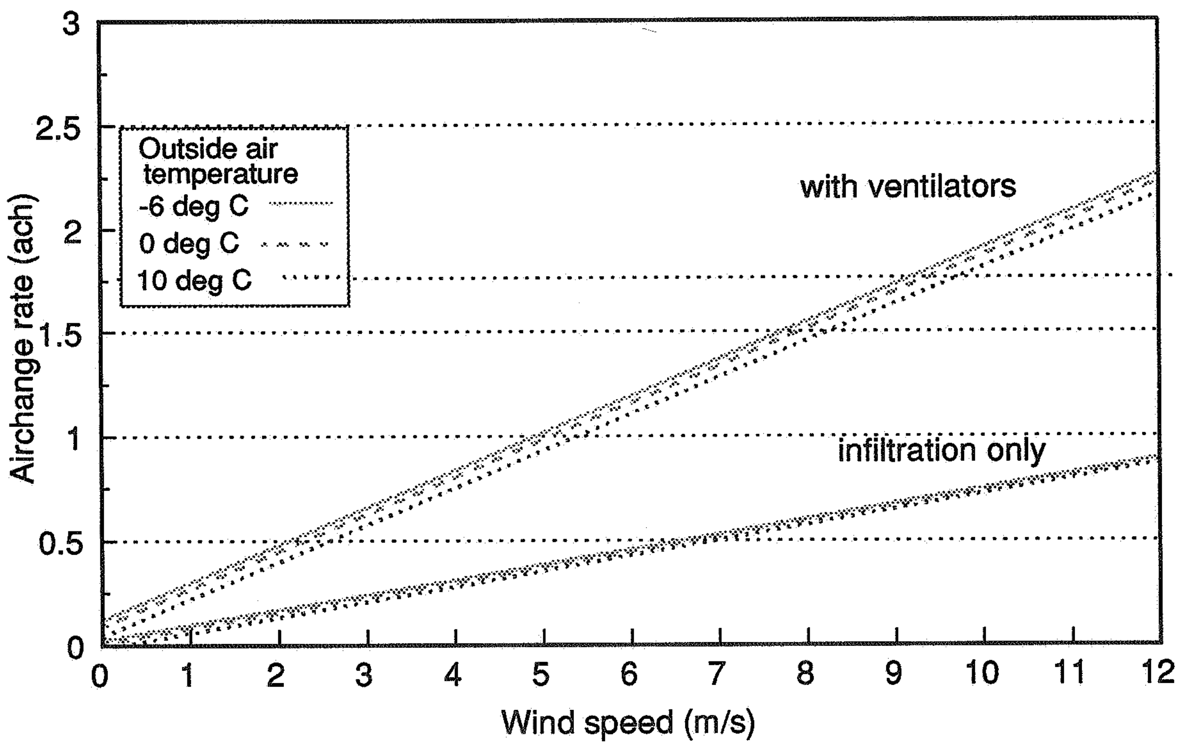

Figure 6. Effect of wind speed and air temperature

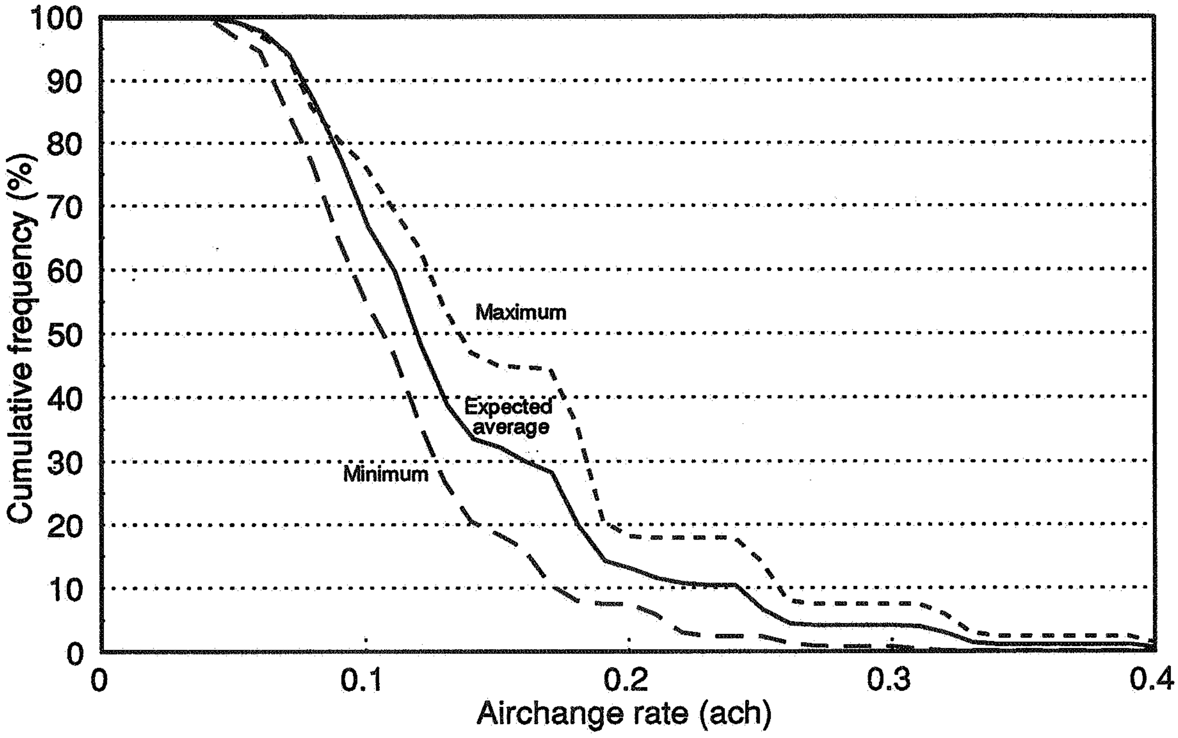

Figure 7. Ventilation performance envelope

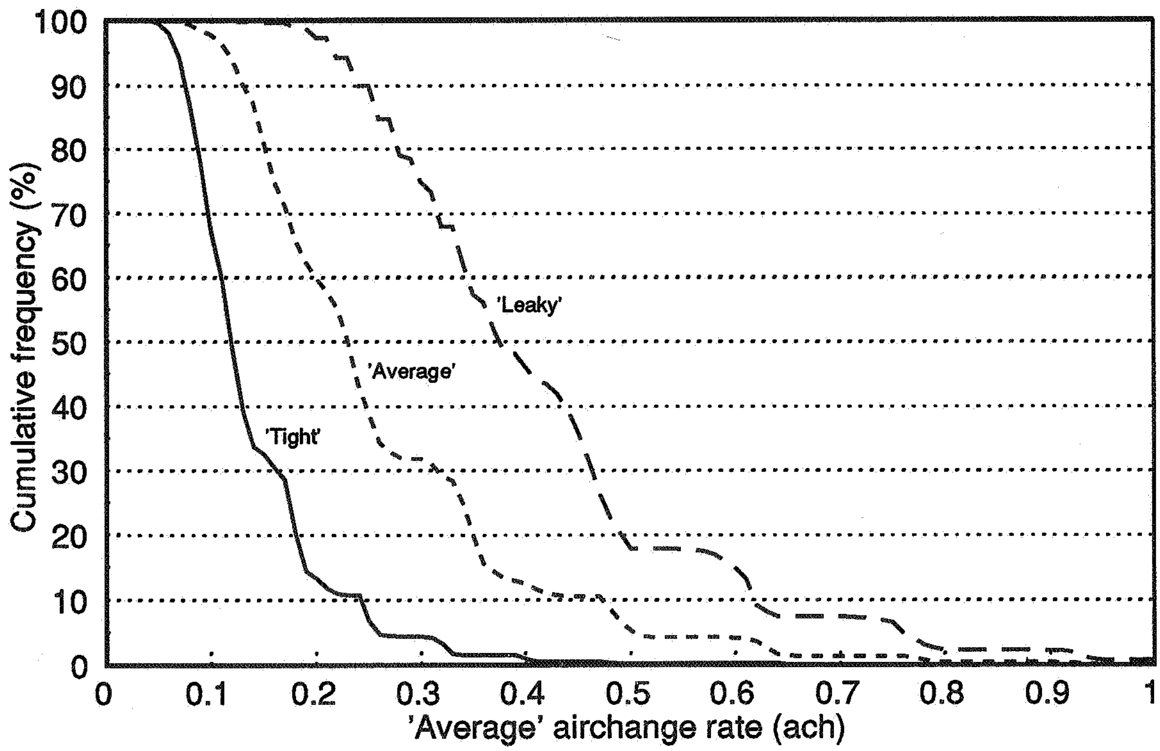

Figure 8. Effect of envelope tightness on ventilation

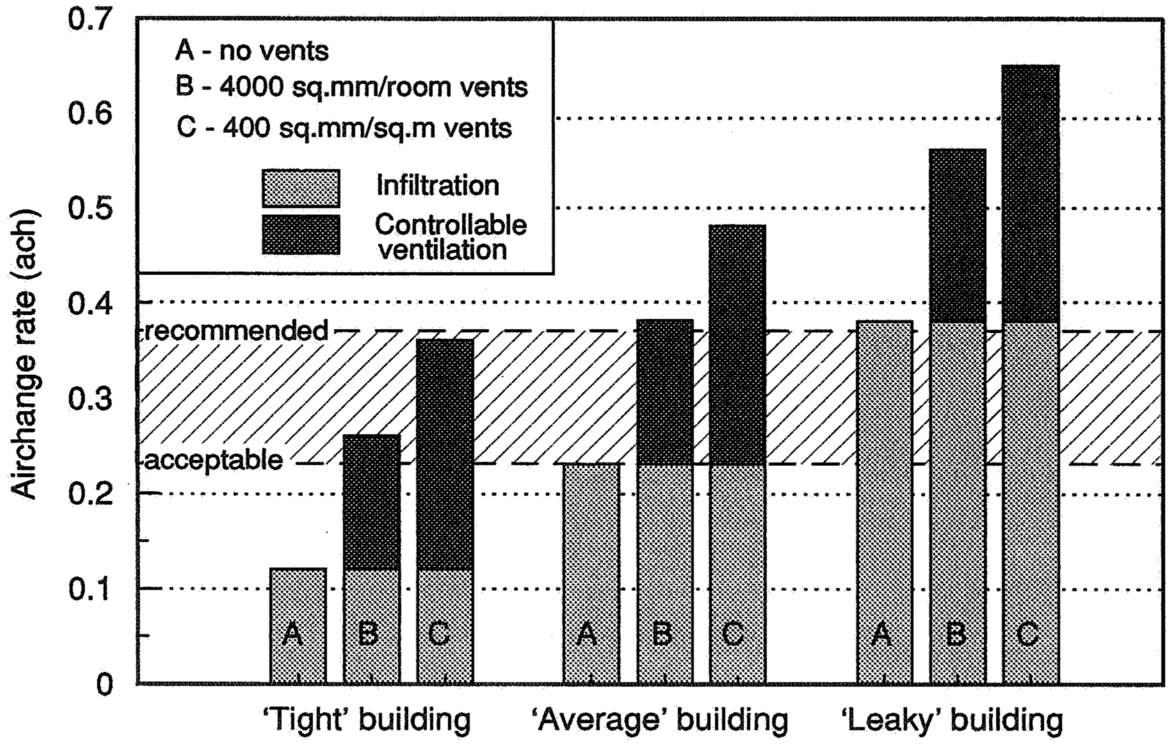

Figure 9. Effect of ventilators and envelope tightness

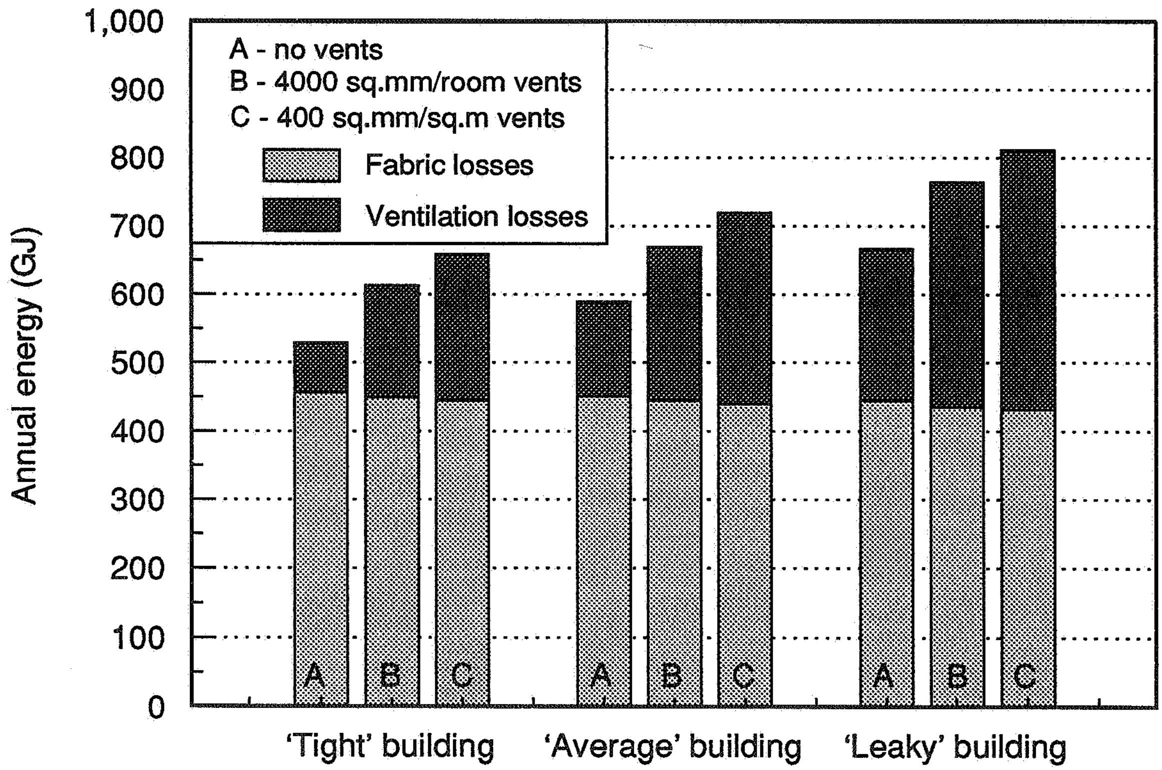

Figure 10. Space heating requirements

APPENDIX 1 - Building data for space heating requirement calculations

Type

Office block, low-rise, cellular

Dimensions

Length	60 m
Width	12 m
Height	9 m approx. (overall); (three storeys, each 2.6 m floor-to-ceiling)

Partitions

Two partitions, full length of building, separating central corridor from office space plus 28 lateral partitions to divide spaces into separate offices (all floors nominally identical).

Windows

Double glazed, with aluminium frames and horizontally pivoted. Glazing amounts to 30% and 45% of wall area in the north- and south-facing facades respectively. Glazing accounts for about 35% in the other two facades.

Orientation

Major axis pointing E - W.

U-values

Walls	0.45 W/m^2 K
Roof	0.60 W/m^2 K
Glass	4.50 W/m^2 K
Ground floor	0.20 W/m^2 K

Y-values

Structural walls	0.73 W/m^2 K
Ceiling/roof	2.00 W/m^2 K
Ground floor	3.00 W/m^2 K
Intermediate floors	2.00 W/m^2 K
Partitions	3.50 W/m^2 K

Location

Garston in Hertfordshire (semi-suburban, partly shaded)

Occupied period

Daily	9 hours
Weekly	5 days
Annually	52 weeks

Total working days per year: 252 days

Design conditions

Inside temperature 18.5°C