Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

# Proximity Effects: Air Infiltration and Ventilation Heat Loss of a Low-Rise Office Block Near a Tall Slab Building

M D A E S Perera,* R Kaleem,** A D Penwarden,* R G Tull*

* Building Research Establishment, Garston, Watford WD2 7JR, UK
** Department of Physics, Brunel University, Uxbridge KUB8 3PH, UK

## SUMMARY

In the mid-1980s, two London architects postulated that deflection of higher speed air from tall slab buildings could increase air infiltration from a neighbouring low-rise block, increasing its associated ventilation heat loss. These issues have been of much concern during the past two decades among designers, developers and local authorities; especially those considering in-fill near tall buildings.

This preliminary study looks at the ventilation and space-heating loss of a three-storey low-rise office block located near a taller nine-storey slab building. A multi-zoned prediction program is used to determine the air infiltration through the envelope of the low building and ventilation through its purpose-provided trickle ventilators. Measurements carried out in the Building Research Establishment's Environmental Wind Tunnel provide the necessary input data on surface wind pressure coefficients.

The wind tunnel measurements show that a tall building near to (and in line with) a low building markedly changes the distributions of wind pressures on the latter. Analysis carried out here confirms that this near-proximity does have an impact on ventilation. Compared with an isolated building:

(a) ventilation rates are reduced by as much as 35% for winds blowing normal to the front (broad) face,
(b) the average ventilation rates expected during the heating season are reduced by about 15% if the buildings are on an open site and by 10% if sheltered. However, adequate ventilation for occupants is met by using the controllable trickle ventilators, and
(c) overall space-heating requirements are marginally increased by 3% as a result of higher convective losses offsetting the reduced ventilation losses.

## 1. INTRODUCTION

Tall slab buildings can create undesirable wind environments at ground level [1] by deflecting downwards the higher speeds encountered at the upper levels. In certain instances, a low-rise block located windward of a tall building not only stabilises the horizontal-axis vortex formed in front of the tall building (Figure 1) but also enhances its strength.

In the mid-1980s, two London architects postulated [2] that deflection of higher speed air from tall slab buildings could increase air infiltration from a neighbouring low-rise block thereby increasing its associated ventilation heat loss. These issues have been of considerable concern during the past two decades to designers, developers and local authorities, especially those considering in-fill near tall buildings.

The study reported here looks at ventilation and space-heating loss during the heating season of a three-storey low-rise office block located near a taller nine-storey slab building. To take into account infiltration losses, this study also looks at the effect different levels of envelope leakage have on this 'proximity effect'.

This study uses the BRE multi-zoned prediction program BREEZE to determine the air infiltration through the building envelope and ventilation airflows through purpose-provided trickle ventilators. Measurements were carried out in the BRE Environmental Wind Tunnel to obtain the surface wind pressure coefficient data necessary for these predictions.

The expected ventilation performance (i.e. how often various ventilation rates are expected during occupied periods) of the building were obtained by combining the predicted ventilation characteristics with weather statistics at the building site. Space heating calculations were carried out using the expected average airchange rates in a standard CIBSE [3] design procedure.

## 2. PREDICTION SET-UP

The BRE multi-celled ventilation prediction program BREEZE was used to carry out this study. This program has been previously validated with full-scale measurements [4]. In the program, the building is taken to have a number of interconnected zones, each at a specific pressure, with air moving from regions of high to low pressures. All internal doors were kept open in the simulations carried out in this study.

Pressure differentials are set up by both the action of wind on the external surface of the building and the temperature difference between inside and outside air. 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 obtain an interior static pressure within the building by requiring that the inflows and outflows for each zone balance.

BREEZE incorporates an algorithm which accounts for infiltration through the external envelope[5] and a unique implementing method for multi-celled buildings. Background leakage is modelled as leakage distributed over the whole of the permeable envelope.

### 2.1. Low-rise Building

The low-rise building chosen for the study is the BRE low-energy office, which has been the subject of extensive heating, ventilation and energy-saving tests [6]. It is similar in form and size to many low-rise, medium-sized and naturally-ventilated office buildings in the UK. This three-storey building (Figure 2) is rectangular (60 m x 12 m) in plan with floor-to-ceiling heights of 2.6 m.

Offices are located on each floor along either side of a central corridor running along east-west. The main entrance to the building is on the north-facing facade. The estimated total volume of the building is 5430 $m^3$ and the external surface area is 1930 $m^2$.

***Envelope leakage***

Previous work [7] indicated that it is possible to categorise the airtightness of UK buildings as either 'tight', 'average' or 'leaky' if the air leakage Q through the envelope is respectively 5, 10 or 20 $m^3/h$ per $m^2$ (of envelope area) when a pressure differential $\Delta p$ of 25 Pa is maintained across it.

For use within the prediction program, the above values were translated to the form of the power-law equation

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

where n was set at 0.6 and the value of k was varied to simulate different envelope airtightness. This leakage was evenly distributed throughout the outside walls and roof.

***Purpose-provided openings***

Previous work [8] showed that, during the heating season, trickle-ventilators with openable areas of 400 $mm^2$ per $m^2$ (of floor area) can provide adequate background ventilation to satisfy fresh air requirements for metabolic needs of occupants and to control body odour. Therefore, for this study, trickle-ventilators with appropriate openable areas were incorporated into the building envelope in each room.

The relationship between volume airflow rate, $q$ and pressure difference $\Delta p$ for these devices were taken to be [9]:

$$q = A C_d \sqrt{\frac{2 \Delta p}{\rho}}$$

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

## 2.2. Wind Tunnel Tests

Surface wind pressure coefficients for use in the prediction procedure were obtained by carrying out wind tunnel tests using 1:200 scale models of the three-storey, 9m high building and a nine-storey, 27m high building with a similar plan form. With the two buildings in-line and their long faces parallel to each other, the following proximity configurations were tested:

(1) low building on its own,

(2) low building with tall building at a separation of 27m (the height of the tall building)

(3) low building with tall building at a separation of 9m (the height of the low building).

The pressure-tapped model of the low building, together with the nearby tall building model 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 suburban terrain at a scale of 1:200. Fuller details of the simulation are given in reference [10].

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 [11]. For each of 12 wind directions at 30° intervals, the pressure coefficients at all the tappings on the low building were obtained by normalising the measured pressures by the reference dynamic pressure. This reference was measured at roof-height of the low building and well upstream of the model.

Figure 3 is a schematic of some of the pressure coefficients obtained at a mid-section position on the low building. This clearly shows the effect of the tall building on the pressure distributions. With the tall building downwind, its front face deflects down to ground level (Figure 1) the high-speed winds at the upper levels. These then impact on the rear (leeward) face of the low building. As a result, the previously negative (suction) pressures on the leeward side of the isolated low building become positive pressures. These positive pressures are greater at the closer spacing of the buildings. Roof pressures also change in a similar manner.

With the tall building upwind, the changes occur on the pressures on the front (windward) face of the low building. Pressures which were positive on the isolated building become negative and the magnitude of these negative pressures is greater at the closer spacing. Roof pressures, although still negative, are more uniformly distributed.

### 2.3. Weather Data

The BRE low-energy office at Garston 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 nearest convenient meteorological station at Heathrow.

The data so obtained were constrained to the winter heating season, from the beginning of October to end of March and to the 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 [3].

Previous work [8] showed that, during this restricted period, winds from the south-west predominate and that an outside air temperature of 9.3°C is exceeded for 50% of the time. Following a standard calculation procedure [12], wind speeds at the site were reduced to 62% of that recorded at Heathrow to account for change of terrain. Figure 4 shows the cumulative frequency distribution of wind speed, both at the open site at Heathrow and that expected at Garston. The wind speed exceeded for 50% of the time at Garston is 2.4 m/s.

## 3. VENTILATION PREDICTION

With the internal temperature of the low building set at 18.5°C (Appendix 1), BREEZE prediction procedures were carried out for all combinations of the following:

(1) different proximity configurations as identified in Section 2.2,
(2) varying envelope tightness (leaky, average or tight),
(3) ventilation solely by infiltration or combined with openable trickle-ventilators,
(4) wind from four directions (0, 30, 60 and 90°N) with the building orientation set so that the front face of the low building faces north,
(5) two external air temperatures of -6°C and 16°C, and
(6) varying wind speed from calm to 12 m/s.

While all the results are available and have been used in the following calculations, only individual results which represent some of the features salient to the current argument are presented here.

### 3.1. Effect of Wind and Air Temperature

Figure 5 shows the variation of airchange rate versus wind speed for the isolated low building. The example shown is for the building with an average envelope leakiness, for the cases where trickle-ventilators are open and closed. The figure shows that, as expected (and away from the low wind speed region), airchange rate increases (approximately linearly) with wind speed.

The maximum ventilation of the isolated low building occurs, as expected [8], when the wind blows directly (from 0°N) onto the North-facing front facade. At any wind speed and temperature difference, the ventilation rate progressively falls as the wind veers, with the minimum rate occurring when the wind blows parallel to the long face.

With the tall building nearby, changes in wind pressure coefficients result in a general lowering of the ventilation rates, and the maximum rates do not necessarily occur for 0°N winds but, in some instances, for winds from 30°N and 60°N.

Although it is not as marked as with wind speed, the inside/outside air temperature difference also has an effect on the ventilation, but it affects the airchange rate more at lower wind speeds. The effect on the airchange rate of outside air temperatures other than the outer limits of -6°C and 16°C is satisfactorily obtained by using an interpolating procedure based on the square root of the temperature difference [11].

In ventilation provision, it is necessary to allow a broad band of ventilation rates which can be controlled by occupants. Following work previously presented [8], Figure 5 shows that openable trickle-ventilators provide a large (double in this instance) <u>controllable</u> ventilation component to the uncontrollable background infiltration.

### 3.2. Proximity Effect of the Tall Building

Figure 6 is a typical result of these tests and shows that the tall building near the low building reduces the ventilation rate of the latter. This is most marked at higher wind speeds and above the low-wind speed regime (within which stack, rather than wind-induced ventilation dominates).

As expected, the tall building upwind of the low building reduces the (wind-induced) ventilation rate of the latter. What was not foreseen but became obvious from the measured pressure coefficients (Section 2.2), is that a similar reduction is induced even when the tall building is downwind of the low building. For example, Figure 6 shows that at a wind speed of 4 m/s, the ventilation rate of the low building is reduced by as much as 35%.

However, these reductions are maxima and usually occur when the wind is normal or near-normal to the long faces of the buildings. These reductions are very much less when the wind blows parallel (i.e. 90°N) to the long faces.

## 4. VENTILATION PERFORMANCE

To assess the ventilation performance and to predict how often various levels of ventilation could be expected, the predicted ventilation characteristics were combined with the weather frequency distribution (Section 2.3), i.e. the concurrence of wind direction, wind speed, and outside air temperature during occupancy.

Using a procedure previously outlined [8], the expected performance envelopes were derived for each of the proximity and airtightness configurations. As an example, Figure 7 shows the expected ventilation performance when the building is isolated and sited in an open- and a sheltered-location.

***Site exposure***

To assess the impact of site exposure on the 'proximity' effect, weather data relevant to a sheltered location (Garston) and an open site (Heathrow) were used in this analysis. Figures 8a and 8b summarise the results for the two sites and show the effect of proximity of the tall building on the low building (with differing envelope airtightness).

The results show that site exposure contributes significantly to the expected 50% 'average' ventilation rates. As a result of the more frequent higher speed winds in the open site, the ventilation rates are much higher (nearly double) than when the building is sheltered. The effect of the envelope air tightness on the ventilation performance is as expected (i.e. the tighter the envelope, the lower the infiltration) and conforms to differences noted in an earlier publication [8].

***Proximity of tall building***

For the two separations tested, the tall building reduces the average ventilation rate from what would be expected if the low office was isolated. This reduction is about 15% for the open site and 10% for the sheltered location. Neither the different envelope air tightness nor the distance between the two buildings substantially alters these reductions.

***Adequacy of ventilation***

The BRE low energy office building accommodates about 70 occupants. To assess whether adequate ventilation is obtained in the above circumstances, Figure 8 also shows the recommended airchange rate (0.37 ach) as well as the minimum allowable (0.23 ach) for this building. These values are based on the CIBSE [13] recommended fresh air rates of 8 l/s per person and a minimum allowable of 5 l/s per person. Inspection of the relevant figures show that, whether the building is isolated or is in close proximity to a tall building, the required minimum ventilation can always be provided through controllable trickle ventilators.

## 5. SPACE HEATING REQUIREMENTS

During the heating season, both air infiltration and provision of controlled ventilation impose a demand on the space heating requirement for the building. To identify the extent of this demand, a standard CIBSE design procedure [3] was used. Appendix 1 contains the data used in the calculations.

Space heating requirements were calculated for all building proximity configurations, envelope airtightness and exposure. As an example, Figure 9 shows the space heating required for the building with an 'average' airtight envelope. Each of the bars within this graph is split between fabric and ventilation losses to clearly identify the influence of ventilation on the overall requirements.

***Effect of openable vents***
For a low-rise building in a sheltered location, but away from any tall building, infiltration (with the vents closed) accounts for about 20% of the overall space heating requirement. As all vents are opened to provide controlled ventilation (from an infiltration rate of 0.22 ach to a ventilation rate of 0.42 ach) to satisfy occupant needs, ventilation losses increase the total space heating requirement by about 20% (with the ventilation-to-fabric loss ratio split in a 35:65 ratio). This configuration will now be used as the 'base' case for further comparison.

***Proximity effect***
With a tall building in close proximity, the 'average' ventilation rate for the base case falls from 0.42 ach to 0.37 ach. As a result, ventilation induced heat losses are marginally reduced resulting in a 4% reduction of the total requirement.

However, this analysis did not take into account the higher convective heat losses expected on the rear facade (facing the tall building) resulting from enhanced exposure to the higher winds deflected downwards. If this is taken into account and the U-value associated with this rear face is increased (Appendix 1) according to currently available CIBSE guidance [13], the overall requirement is now increased by just 3%.

***Site exposure***
If the building is now located in an open site, the average ventilation nearly doubles to 0.70 ach (Section 4). Consequently ventilation heat losses increase total losses by 16%.

## 6. DISCUSSION AND CONCLUSIONS

This preliminary study was carried out to assess ventilation and the space-heating loss during the heating season of a low-rise office block located near a tall building. As part of the study, the effect of the airtightness of the low building and whether or not it was located in a sheltered site was also considered.

Wind tunnel tests were carried out on the low building to determine surface wind pressure coefficients as data input to a ventilation prediction procedure. Measurements showed that the proximity of a tall building can dramatically change, both in magnitude and sign, pressure coefficients usually expected from published isolated-building data.

With the wind blowing normal to the front face of the low building and with the tall building downwind deflecting downwards the high-speed winds at the upper levels, the most distinct change was in the pressures on the leeward face of the low building. This was a result of the downwards deflected high-speed winds impacting on the rear face of the low building; and inducing positive pressures on what, otherwise, would be a suction area.

The consequence of this was that the predicted ventilation fell by as much as 35% compared with rates predicted for the building in isolation. These reductions occurred when the wind blew normal (or nearly normal) to the front (broad) face of the low building. However, these changes did not occur with winds blowing parallel to the long faces of the two buildings.

The 'average' ventilation rates expected for 50% of the time during the heating season (and when the building is occupied) were evaluated using concurrent wind speed, wind direction and air temperature meteorological data. Results indicated that the 'proximity' effect reduces the 'average' rate by about 15% if the buildings are located in an open site and by 10% if sheltered. However, the required minimum ventilation rate for occupants can always be met by using controllable trickle ventilation.

The 'proximity' effect on the space heating requirement for the low building was assessed. Analysis showed that while the lower 'average' ventilation rate reduced (by 4%) the heating requirement, this was offset by the higher fabric loss from the rear face of the buildings. The analysis predicted a slight overall increase of just 3%.

In conclusion, preliminary analysis shows that a tall building in near proximity to and in-line with a low-rise building has an impact on the ventilation of the latter. Compared with an isolated building:

(a) ventilation rates of the low building can be reduced by as much as 35% for winds blowing normal to the front (broad) face,
(b) average ventilation rates expected during the heating season can be reduced by 15% if it is an open site and by 10% if sheltered, and
(c) overall space-heating requirements are marginally increased by 3% as a result of higher convective losses offsetting the reduced ventilation losses.


## ACKNOWLEDGEMENTS

Thanks to Dr Eric Solomon of Engineering Computations for modifying and updating the BREEZE program to handle as effectively as possible the 5,000 or so separate computer runs necessary for this study.


## REFERENCES


1. **Penwarden A D and Wise A F E.** *Wind environment around buildings.* Building Research Establishment Report, HMSO, 1975.

2. **Gerry U K and Harvey G P.** *The abatement of wind nuisance in the vicinity of tower blocks.* Greater London Council Reviews and Studies Series 18, 1983.

3. **CIBS.** *Calculation of Energy Demands and Targets for the Design of New Buildings and Services.* CIBS Building Energy Code 2(a), London: Chartered Institution of Building Services Engineers, 1981.

4. **Perera M D A E S, Walker R R, Hathaway M B, Oglesby O D and Warren P R.** *Natural ventilation in large and multicelled buildings: Theory, measurement and prediction.* Commission of the European Communities Report EUR 10552 EN, 1986.

5. **Perera M D A E S, Powell G, Walker R R and Jones P J.** Ventilation performance of large buildings: Prediction using pressurisation measurements. *Building Services Engineering Research and Technology,* 1991, 12(3), 95-102.

6. **Crisp V H, Fisk D J and Salvidge A C.** *The BRE Low-energy Office.* Garston, BRE, 1984.

7. **Perera M D A E S and Parkins L M.** Airtightness of UK buildings: status and future possibilities. *Environmental Policy and Practice,* 1992, **11** (2).

8. **Perera M D A E S.** Controlled background ventilation for large commercial buildings. *Proceedings of the 13th AIVC Conference on Ventilation for Energy Efficiency and Optimum Indoor Air Quality, 1992.*

9. **Building Research Establishment.** Principles of Natural Ventilation. BRE Digest 210. Garston, BRE, 1978.

10. **Perera M D A E S.** Shelter behind two-dimensional solid and porous fences. *Journal of Wind Engineering and Industrial Aerodynamics,* 1981, 8 89-104.

11. **Perera M D A E S, Tull R G and Walker R R.** Natural ventilation for a Crown court: developing statistical assessment techniques at the design stage. *Proceedings of the 9th AIVC Conference on Effective Ventilation, 1988.*

12. **British Standards Institution.** Code of practice for ventilation principles and designing for natural ventilation. *British Standard* BS 5925:1991, London, BSI, 1991.

13. **The Chartered Institution of Building Services Engineers.** *CIBSE Guide, Volumes A and B,* 1988.

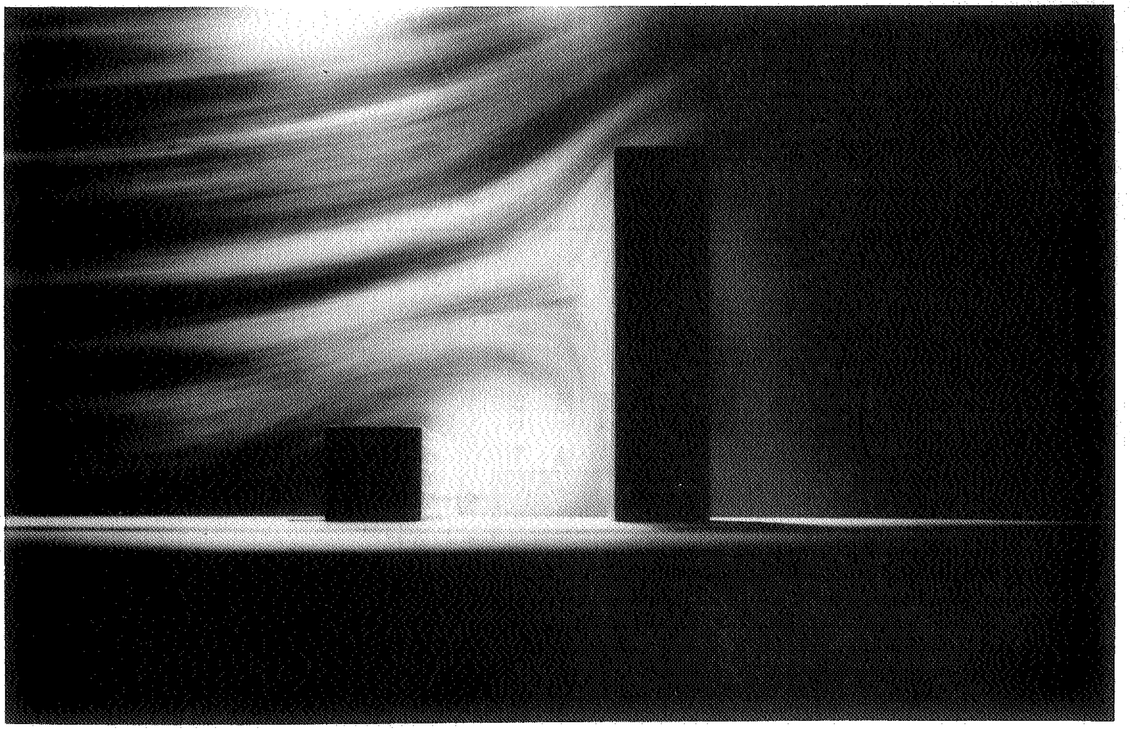

**Figure 1 - Typical airflow around model of tall building**

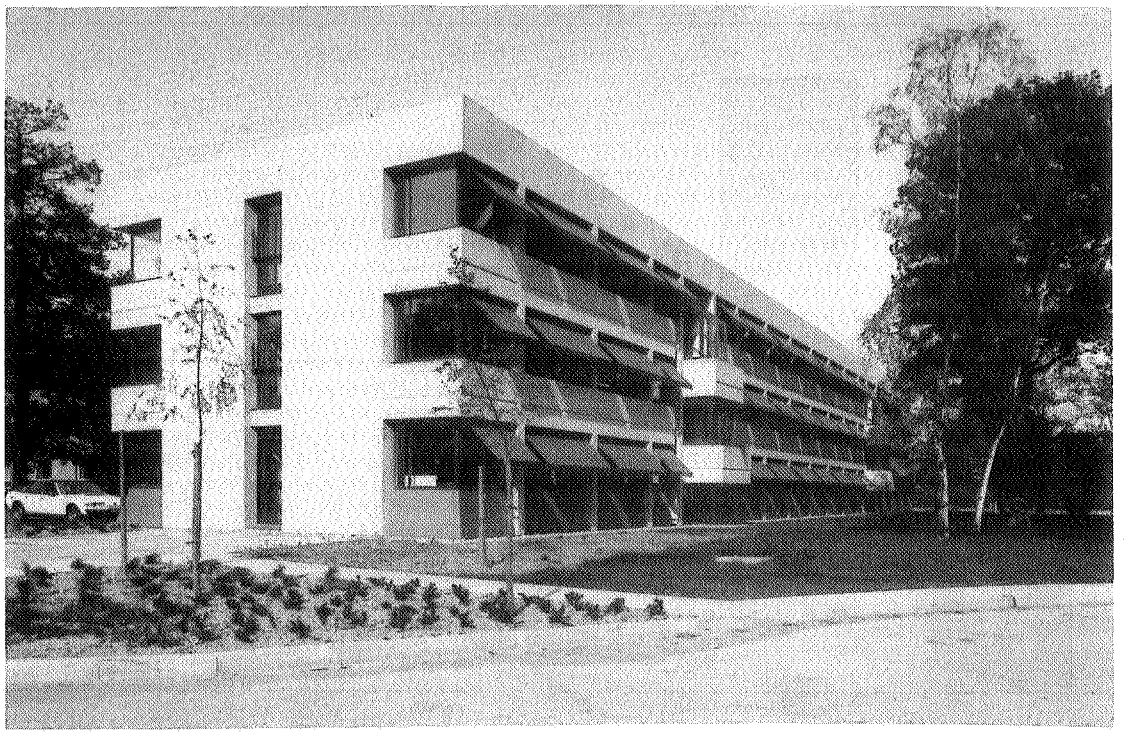

**Figure 2 - View of LEO building from south-east**

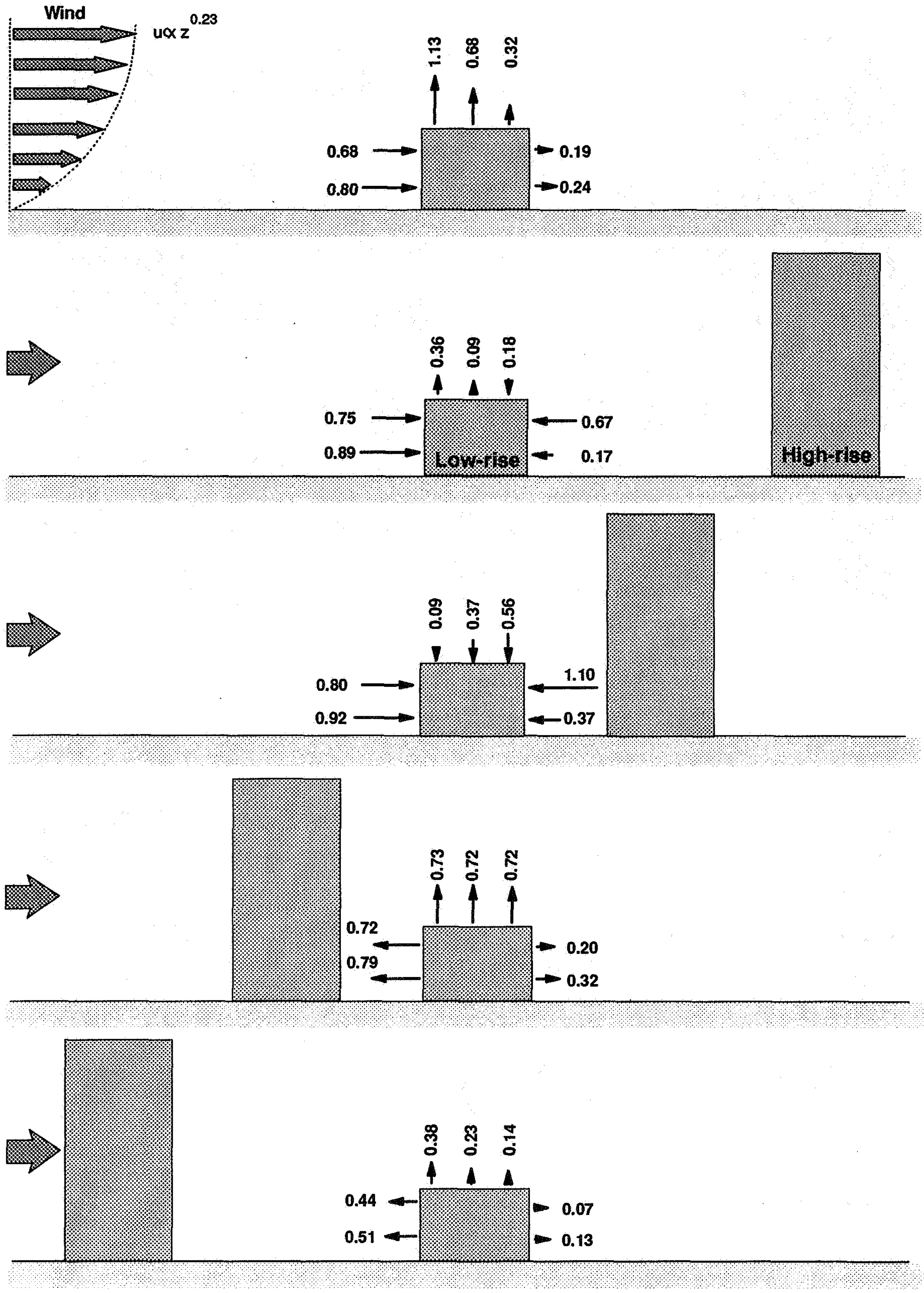


**Figure 3 - Wind pressure coefficients on centre-section of low rise with wind normal to long face.**

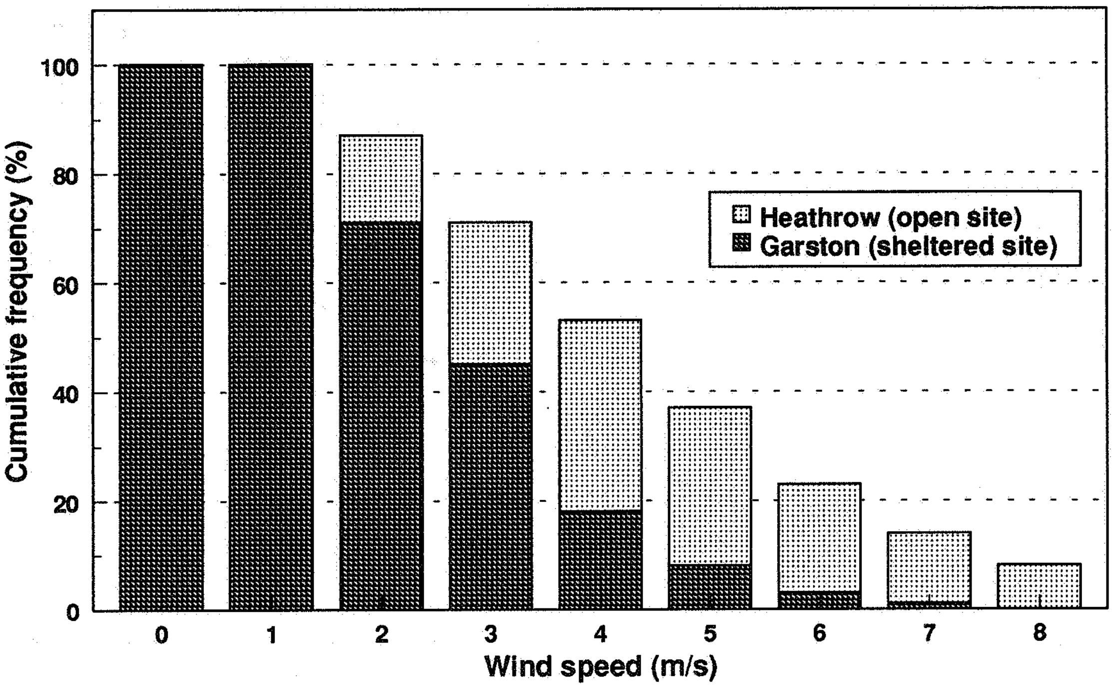


**Figure 4 - Wind speed at Heathrow and Garston**

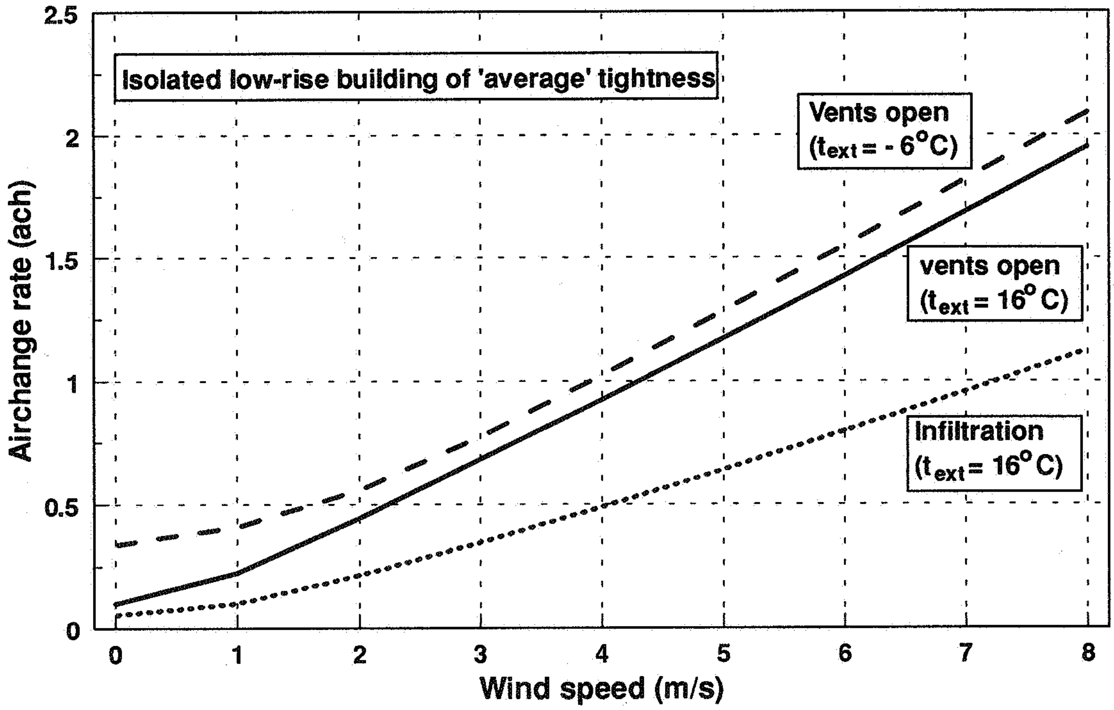


**Figure 5 - Effect of wind speed and outside air temperature**

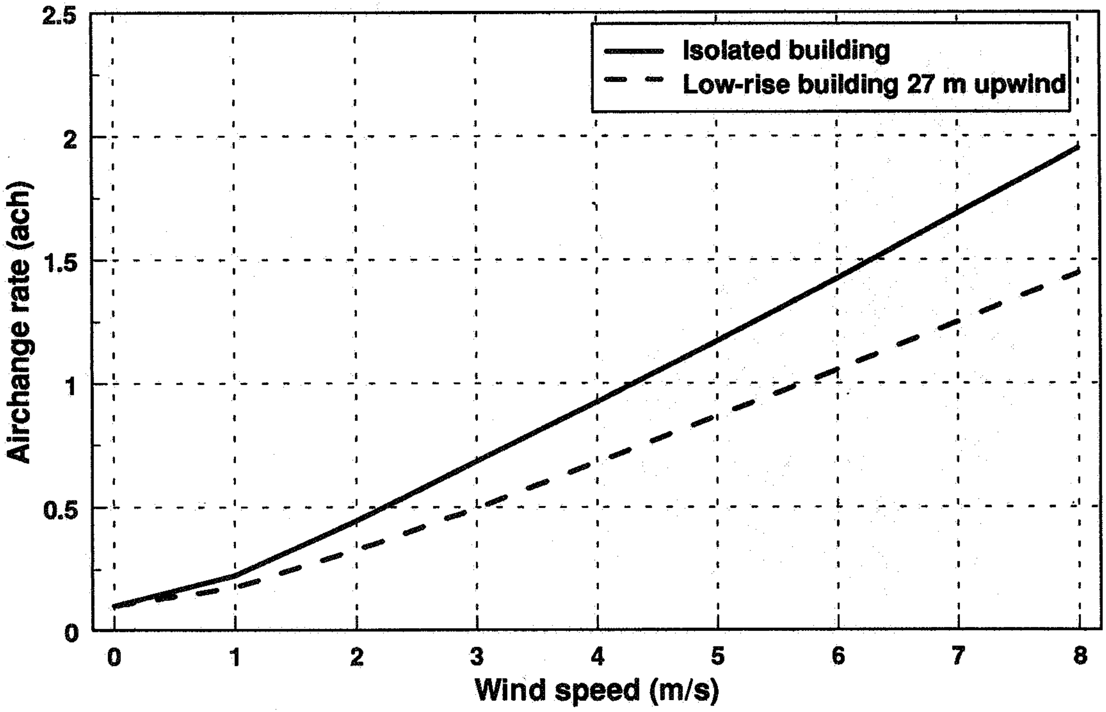


**Figure 6 - Proximity effect on ventilation rate**

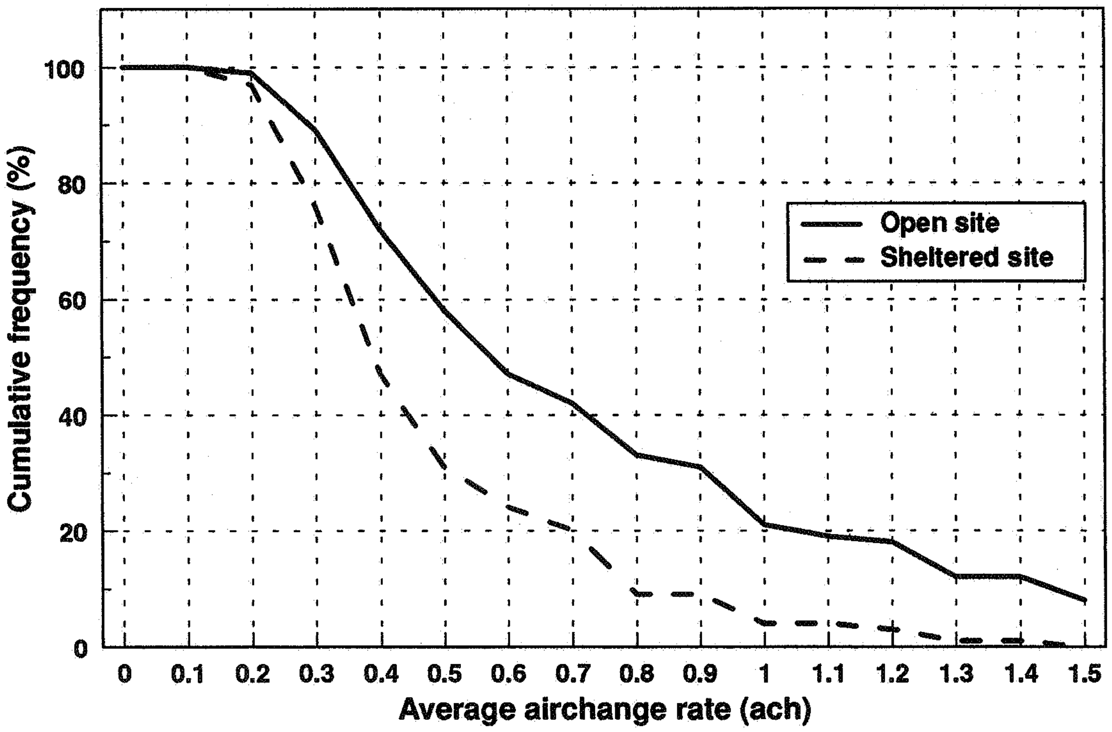


**Figure 7 - Predicted ventilation performance**

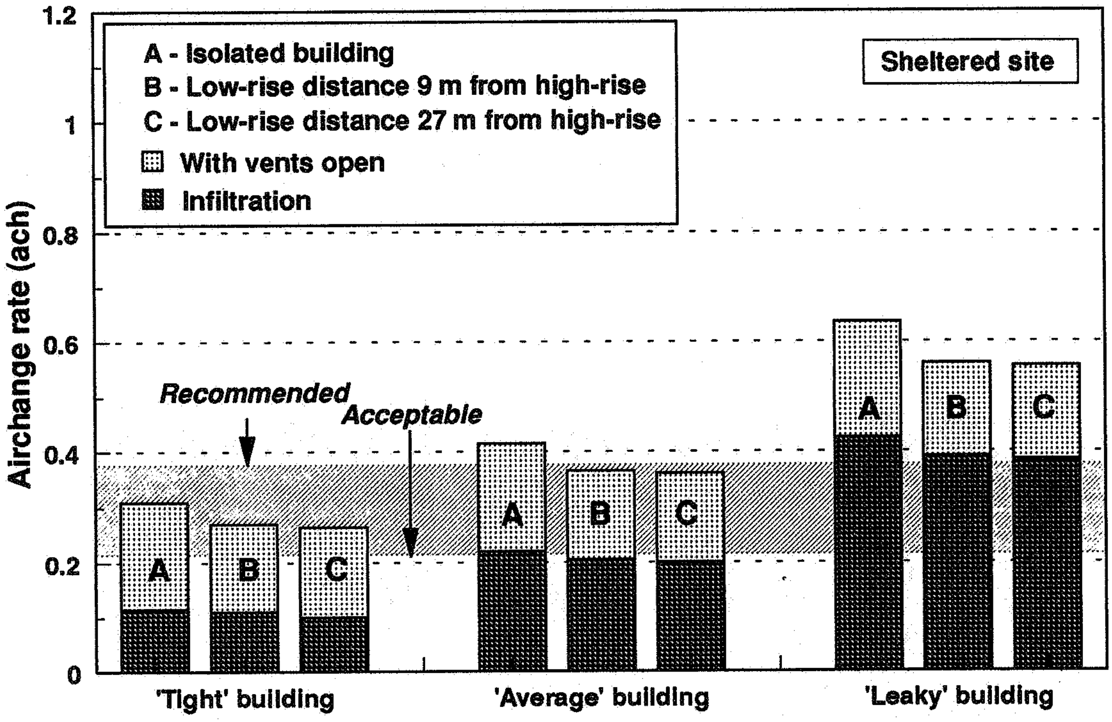


Figure 8.a - Airchange rates exceeded for 50% of the time

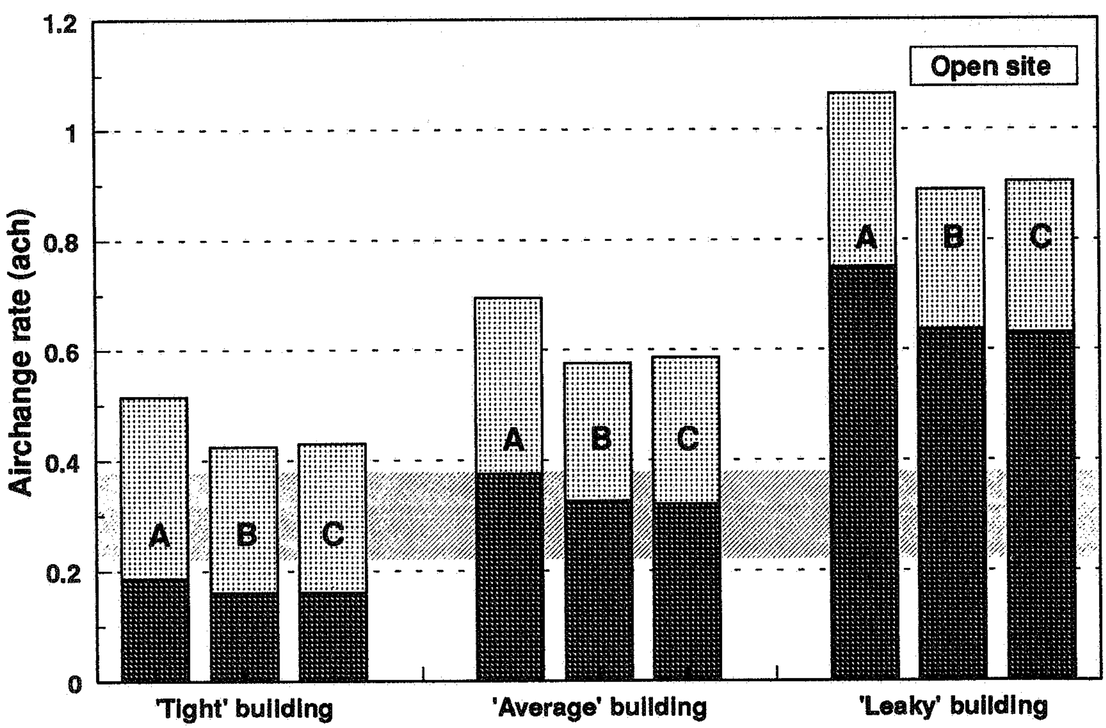


Figure 8.b - Airchange rates exceeded for 50% of the time

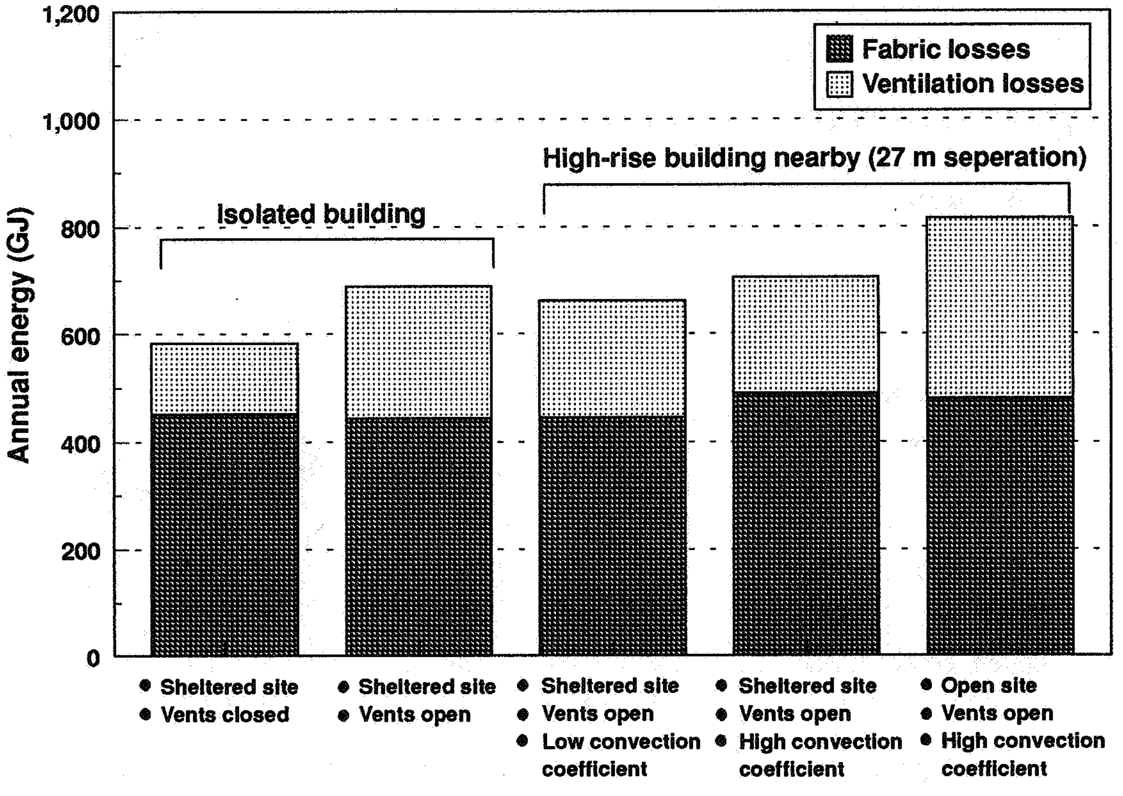


Figure 9 - Space heating requirements for 'average' building

## 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 |

(Note: U-values of the south wall and south glazing are increased to 0.46 and 5.5 $W/m^2$ K when the tall building is in close proximity)

*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, 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