Guidance Note GN 7/2000

MAKING NATURAL VENTILATION WORK

Andrew Martin
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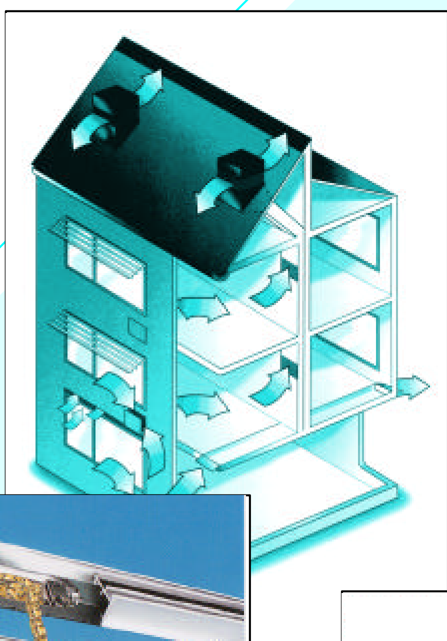


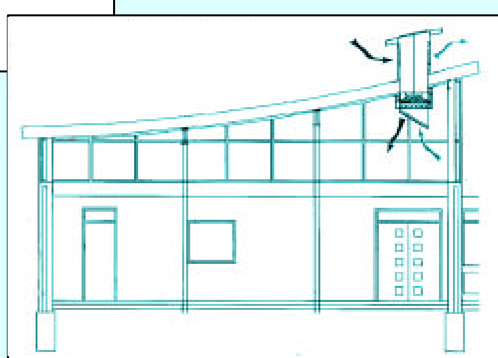

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ACKNOWLEDGEMENTS

This work was performed under contract to the Department of the Environment, Transport and the Regions, under the ‘Partners in Innovation’ programme. BSRIA acknowledges the financial support of the Department of the Environment, Transport and the Regions and would like to thank the following sponsors for their contribution which has led to the production of this Guidance Note:

Department of the Environment, Transport and the Regions

Bhs PLC
Colt International Ltd
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EXECUTIVE SUMMARY

Interest in natural ventilation for non-domestic buildings has increased significantly in recent years. It is fast becoming an attractive design alternative for providing acceptable indoor air quality rather than the more traditional approach of using mechanical ventilation. In some buildings, natural ventilation can also be used as an alternative to air conditioning plant to provide cooling. There are now a number of buildings in use in the UK that have been designed to make better use of natural ventilation in place of an air conditioning system.

This increased uptake of natural ventilation in buildings is due to the benefits offered:

- capital costs in the region of 10-15% lower than air-conditioned equivalents[1]
- lower operating costs (energy and maintenance)
- simpler and more manageable environmental control systems due to the building envelope acting as the primary climate modifier
- reduced environmental impact through the elimination of mechanical ventilation and refrigerant air conditioning
- productivity improvements due to occupants preferences to control their own ventilation rate
- increased robustness, flexibility and adaptability.

Although naturally ventilated buildings provide these benefits the increased implementation of natural ventilation is threatened by poor management and operation of natural ventilation strategies. Unfortunately, many buildings do not perform as well as intended in respect of natural ventilation. Occupants complain of draughts, poor air quality and summer overheating and facilities managers are concerned about higher than expected energy consumption. In some instances these problems relate to fundamental design shortcomings. However, in the majority of cases problems either stem from, or are greatly influenced by, factors concerning the management and operation of the natural ventilation strategy.

This Guidance Note provides information for building managers and occupants to address these issues and optimise their natural ventilation systems. The guidance has been developed from discussions with facilities managers and building services engineers as well as from BSRIA's own experiences and consideration of other published material. Case studies have been developed to illustrate particular points, and details of natural ventilation related products are provided in the appendices.

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1 INTRODUCTION

The provision of a reasonable internal environment involves many issues. Many comfort related problems in naturally ventilated buildings arise from factors concerning the management and operation of the natural ventilation strategy. Occupants complain of draughts, poor air quality and summer overheating and facilities managers are concerned about higher than expected energy consumption.

This publication provides guidance for building managers concerning management and operation of natural ventilation in buildings. The document encourages recognition of the causes of poor natural ventilation performance and recommends steps that can be taken to improve performance.

1.1 USING THE DOCUMENT

This document is arranged in two main parts. The first part (section 2) is primarily an introduction to natural ventilation in buildings and effective operation. It is recommended that all users read this section in order to gain a general understanding of the subject prior to reading other relevant information from sections 2 to 7. Section 2 describes:

- the basic requirements of ventilation in buildings, ventilation design and night cooling
- the role of building occupants
- the use of controls and type
- issues affecting natural ventilation performance in particular building types.

The second main part to the document is a series of sections relating to the main operational issues that affect the performance of naturally ventilated buildings.
The headings are:

- general operational issues - section 3
- restricted ventilation and stagnant areas - section 4
- overcooling/draughts - section 5
- non-operation of vents - section 6
- overheating - section 7.

It is intended that users identify their particular concerns from the contents page and then read the text relating to each issue.

Details of different natural ventilation components are highlighted in the appendices.

2 UNDERSTANDING NATURAL VENTILATION

2.1 DEFINITION, DESIGN AND NIGHT COOLING

Natural ventilation makes use of the forces of wind and density difference to move air through a building. A naturally ventilated building should be designed and operated to make use of these forces taking into account the following criteria:

1) The air change rate should be sufficient to provide satisfactory fresh air for occupant health and comfort. This is generally the winter design condition[2].

2) During summer the air change rate should be sufficient to remove heat gains from the space and maintain an adequate level of thermal comfort. The summer ventilation rate is likely to be at least an order of magnitude greater than those required in winter[3].

3) The flow of outside air should be evenly distributed throughout the occupied zone to avoid areas of under or over-cooling and to ensure satisfactory air quality throughout.

4) To avoid nuisance draughts, such as those likely to disturb papers, local air velocities (in summer) should be below 0.8 m/s[4]. ISO 7730[5] recommends that for moderate thermal environments with predominantly sedentary activity, the mean air velocities during winter should be less than 0.15 m/s.

The driving pressures for natural ventilation are very low, typically less than ten pascals, and hence careful design is required to ensure that the air flow path is as intended. It should be remembered that air flows from higher pressure areas to lower pressure areas. The path should be as direct as possible as the available driving forces are often not enough to overcome resistances presented by changes of direction (such as may be created by partitions, filing cabinets, shelving etc.) or a multitude of vents or grilles.

2.1.1 Natural ventilation design

There are a number of different natural ventilation air flow paths in buildings, the three main ones being:

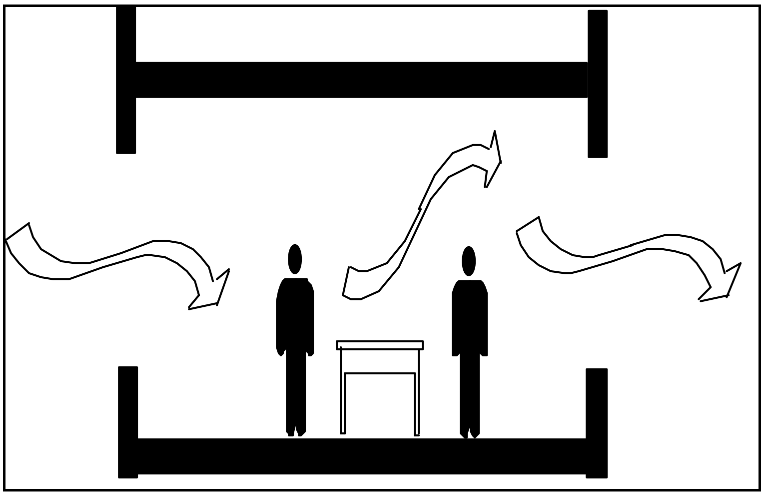
- cross ventilation
- single sided ventilation
- passive stack ventilation.

In order to maximise the effectiveness of a natural ventilation system, it is important that the basic underlying design principles are understood. In this way decisions can be formed on the most appropriate action to take to optimise ventilation performance and associated occupant comfort. The following paragraphs highlight these natural ventilation designs.

Design for cross ventilation

Cross ventilation (see Figure 1) can achieve the highest air change rates, and can ventilate a deeper floor plate (five times the floor-ceiling height) than single sided ventilation. It should therefore be encouraged whenever possible by ensuring a reasonably unobstructed flow path between windows or vents on opposite sides of the building. It is wind-induced pressure differences that drive the air across the building.

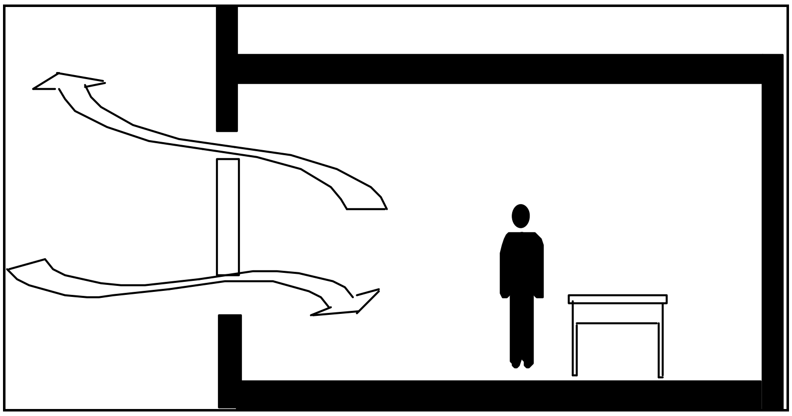
Figure 1
Wind driven ventilation - cross ventilation



Design for single-sided ventilation

Cross ventilation of some spaces may not be possible due to fixed or structural partitioning and may have to rely on single-sided ventilation (see Figure 2). If the windows are designed with this aim in mind, a room depth of up to at least 6 - 7 m can be satisfactorily ventilated in this way.

Figure 2
Wind driven ventilation - single sided ventilation



Windows should be tall or preferably have a top and bottom opening to allow local stack effect to set up a convection circulation, allowing cooler air in through the lower opening and warmer air to exhaust at the top.

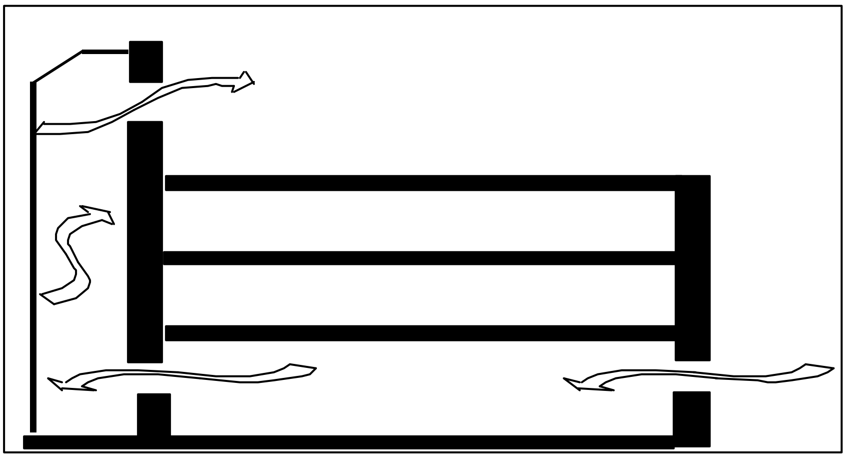
Design for passive stack ventilation

Stack ventilation (see Figure 3) is sometimes used where cross ventilation is not possible, and single-sided ventilation cannot provide a sufficient air change rate.

Stack ventilation (outward air flow) is generally assumed to be driven by temperature differences between the hot air in the occupied space and the cooler external air. However, in peak summer conditions, a good building design, with effective use of thermal capacity and night ventilation, should not have internal temperatures in occupied areas much above ambient, so the stack pressure (assuming no solar assistance) will be minimal. At night, however, when outside temperatures drop, stack ventilation as part of a night cooling strategy can be particularly effective.

Stack ventilation can also be wind driven and in practice this is likely to be the predominant daytime ventilation driving force. Even on very hot days some wind is nearly always present in the UK, the effect of which is likely to be greater than the available stack. Thus, for much of the time, a stack provides a flow path for wind driven ventilation from windows subject to positive pressure, through the room, to the negative pressure area at the stack termination.

Figure 3
Temperature driven ventilation in a stack



For stack ventilation the neutral pressure level[1] (NPL) must be above the window level on the highest floor to be ventilated if air is to flow from the room to the exterior. The top of the stack should be extended to raise the overall height of the stack such that the neutral pressure level is high enough to provide sufficient driving force to draw air out of the building at the top floor. Further information can be found in CIBSE AM10[6].

Mixed mode ventilation

Some buildings may not be suitable for pure natural ventilation due to their depth or other constraints, but may make use of a mixed mode system to minimise mechanical plant requirements. The aim is to use natural ventilation to satisfy the base condition, and to use mechanical plant for peak conditions. Problems can arise due to conflicts between the different modes of operation, for example, windows open at the same time as the mechanical supply is on and careful consideration of the control strategy is required.

1 *The neutral pressure level is the height above ground level where the internal and external pressure gradients are equal with consequently no air flow into or out of the building at this level. Below the neutral pressure level, the internal pressure is less than the external, providing the external temperature is below the internal temperature, and consequently flow will occur into the building. Above the neutral pressure level, the opposite is true, and flow will be out of the building. However, if the internal temperature is less than outside, air flow will be reversed.*

2.1.2 Night cooling

Night cooling is an established technique allowing ventilation to take place at night with the intention of removing heat gains that have built up during the preceding day[7]. By permitting the cool night air to flow through a building, heat is removed and cooling of the building fabric, furniture and fittings is achieved thus providing a cooling effect the following day.

For the majority of buildings there is adequate 'free' cooling available during the day for approximately 90% of the year. For naturally ventilated buildings this is directly from outside, either by opening windows or through opening vents. It is during periods of peak outside air temperatures that night cooling is particularly needed to provide additional cooling.

The principle of night cooling is worthwhile applying to any building with heat gains over approximately 20 W/m^2, below which daytime openings of windows and other vents should provide reasonable temperature conditions for most of the time. The use of solar shading, efficient and well controlled lighting systems and the removal of heat generating equipment (or location adjacent to a ventilation extract) will provide additional heat gain reduction.

For naturally ventilated buildings night cooling can be achieved through various methods including:

- The use of an exposed ceiling slab. Inlet and outlet vents should encourage airflow over the exposed ceiling surface yet should be secure from intruders and prevent rain ingress.

- The use of stack effect. Stack effect has a greater influence at night than during the day since a larger temperature differential will exist between the internal and external temperature at night. However, it is likely that the wind speed will still be the dominant ventilation mechanism.

- Automatic control of windows and other vents. This can be easily carried out since there are actuators available to open and close all types of windows, dampers, doors, rooflights etc. This offers the benefit of being able to carry out night cooling without any manual input. The control system should provide appropriate interlocks to prevent adverse influences on the building. These might include interlocks for high wind speed, rain, low external temperature, wind direction and low internal temperature.

- Using manually openable windows. Some buildings have been designed with the intention of carrying out night cooling using manually openable windows. Secure vents, perhaps protected by grilles etc, may be left open at night to allow ventilation to take place.

2.2 STAFF TRAINING

Two key issues that affect the performance of naturally ventilated buildings are control and a lack of understanding of the ventilation strategy (both occupants and facilities department). Occupants also often fail to understand the link between solar gain, the use of blinds and the constant use of artificial lighting when natural lighting is sufficient. However, some problems are design problems rather than a lack of understanding, for example, if a single opening is intended to provide ventilation for a group of occupants the window may not be opened due to different comfort requirements between occupants.

Training of both those responsible for the operation of the space and the occupants should be undertaken in order to obtain the optimum operating conditions. This is particularly so when staff have previously worked in a mechanically ventilated area as they are less likely to make effective use of the vents and any adjustable solar shading.

Typical training for both parties might include a written 'users guide' and briefing from the architect/building services designer regarding the intended operation of the building. The use of the control system, the blinds and windows, operation of night cooling, the use of natural and artificial lighting, operation of thermostatic control valves etc. should be included. The responsibilities of the occupants in opening windows and trickle vents, shutting blinds, turning off lights etc. should be explained together with the benefits of these actions. Details of the expected temperature conditions throughout the year should be discussed.

Staff responsible for the operation of the building will require more in-depth training in these topics, particularly where automatic controls are applied. Where appropriate, these staff should be involved in the long-term fine tuning of these controls. A detailed written description of the ventilation system and control system design intent and intended operation of the building should be provided in the handover documentation.

2.3 CONTROL

Natural ventilation must be controlled in order to deliver an appropriate flow of air as internal requirements and prevailing climatic conditions vary. The control can either be automatic or manual, or a mixture of the two.

2.3.1 Manual control

Local occupant control of naturally ventilated buildings is the most common means of control. Occupant controls range from conventional (manually) openable windows, to the use of pushbuttons linked to the automatic control system to electrically drive a window or vent open. For example, an office may have a large window under manual control in each bay with an automatically controlled casement vent above to provide night cooling (with day time override controls).

Research has been carried out showing that where occupants of a space have control over their local area they are more willing to accept a wider comfort band[8]. For example, it is suggested that in a fully air conditioned building with no local control and no openable windows, the maximum acceptable temperature is 24^{o}C. However, in an office using natural ventilation with full user control over the window opening and good 'outside awareness', the internal office comfort conditions could rise to 27^{o}C before the same level of complaints would arise[9]. Therefore, it is advantageous to allow staff to control their local environment.

2.3.2 Automatic control

Automatic controls are utilised in a number of different ways. Automatic controls fitted to the inlet and outlet ventilation path allow cooling at night to be undertaken and may also allow improved control of day time ventilation. For example, ventilation can be controlled in relation to internal temperatures; if solar radiation is high, anticipatory control is arranged which increases the ventilation rate before internal temperature rises too much. For buildings that are in heating mode, ventilation rates can be controlled on the basis of CO_2.

The use of a lighting control system may extend this process even further, since it will reduce the heat gains during the peak cooling season (perhaps by 10 W/m^2), when natural light levels will be at their highest.

Automatic controls are not only used to ameliorate heat gains. Some buildings may not be suited to the manual operation of windows, especially public buildings where damage may occur to the vents when they are opened by people unfamiliar with their operation. Other buildings may not have accessible windows, eg atria, sports halls etc.

There are various control components for natural ventilation in buildings including window actuators, damper actuators and various types of sensor.

Automatic control systems may stand alone or can fall within the operation of a Building Management System (BMS). Building Management Systems have the ability to control large number of vents in accordance with both the local zone requirements and in conjunction with the 'site wide' monitoring of other parameters such as the weather and the decision to undertake night cooling.

It is important for facilities managers to be aware that automatic controls should have a manual override so that occupants can still control their environment if the need arises.

Problems that can arise with both automatic and manual controls are dealt with under subsequent chapter headings.

2.4 NATURAL VENTILATION PERFORMANCE ISSUES IN SPECIFIC BUILDINGS

Whilst all the problems that are highlighted in this document can potentially occur in each building type, there are particular issues that affect certain building types more than most. These include:

Offices

- positioning of partitions around perimeter
- poor use of solar shading
- poor light switching arrangements leading to lights remaining on and exacerbated summer overheating
- concentration of high heat gain equipment in unventilated areas.

Shops

- high heat gains (primarily from lighting and people) may lead to overheating
- large entrances may lead to overcooling/draughts in winter
- deep plan of department stores not conducive to natural ventilation.

Schools

- particular need for robust ventilation devices
- staff unsure of operation of high level vents
- no one takes responsibility for operation of vents
- need for trickle ventilation during winter
- entrances often held open for several minutes during break periods and during change of lessons involving pupil movement to other classrooms leading to overcooling in winter.

Hospitals

- occupants are transitory - they are not familiar with operation (opening) of ventilation devices
- curtains and blinds likely to restrict ventilation through windows, particularly where widows have limited opening
- difficulty of operation due to unfamiliarity with, or awkwardness of, the operating mechanism
- nobody takes ownership of window.

3 GENERAL OPERATIONAL ISSUES

The three main issues that fall under this heading are security concerns, building manager issues and controls. Further aspects regarding controls are also mentioned in subsequent sections.

3.1 SECURITY

Security issues are best addressed at the design stage and a 'passive', secure design of window or vent is likely to provide the best solution to prevent unauthorised entry into a building. It may be possible to retrofit devices to allow secure ventilation to take place at night in summer. Devices include restrictors to limit the amount of vent opening, provision of small secure vents in conjunction with large ones, grilles or louvres over vents where no view out is required, eg high level vents.

Problems:	**Solutions:**
• Large, open windows can present a security risk, especially on the ground floor. This can prevent windows being opened, even on upper floors and, despite the presence of security personnel. In particular, security concerns may prevent night cooling strategies being implemented.	• Always obtain insurance company approval before making changes • Re-assess security arrangements and risks associated with opening windows and night ventilation/cooling strategies. If possible put into operation measures for opening windows and/or strategies for night ventilation/cooling. If there are risks then re-assess security strategy. • Adopt suitable window opening designs (see Appendix A), or separate the ventilation element from the window to provide natural ventilation without compromising security. • Check for damaged/faulty security design features. • Consider monitoring the unauthorised opening of windows and vents using contact switches and other detection systems such as presence detectors.

Case Study: Anglia Polytechnic University, Learning Resource Centre[10]

This is a 6000 m^2 building on four levels incorporating a library, plus educational and social facilities. The building makes use of two 'full height' atria with opening rooflights on the sides and openable windows on the perimeter to help ventilate the 30 m deep building.

A large number of computers are provided in the ground floor and due to security concerns only narrow high level (clerestory) windows are used in these areas.

3.2 BUILDING MANAGER ISSUES

Problems:	Solutions:
• Speed of response of building managers to complaints is too slow (from the occupants' viewpoint), building managers have too little authority.	• Re-assess building managers' role and possibly change this in relation to operating natural ventilation. • Give more control to occupants over their own comfort levels.
• Building managers who lack expertise or who are not interested.	• Consider delegation of responsibility to other maintenance staff. Provide further occupant training/awareness.
• There is no one person taking responsibility for the operation of the building.	• A suitable person should be selected to undertake this role.

3.3 CONTROL ISSUES

Problems:	Solutions:
• Facilities managers do not understand control strategy.	• The link between control strategies and facilities managers is important, and although in some cases it is not required that building managers understand every detail of their energy systems, it is important that an understanding is reached on how natural ventilation and associated controls work.
• Control strategy is wrong from design.	• This is most readily indicated by occupant complaints. The controls contractor should review the system operation in conjunction with the facilities personnel.
• Control strategy is wrong because building specification has changed.	• Change control strategy in line with new building specification.

4 RESTRICTED VENTILATION AND STAGNANT AREAS

Many buildings may be adequately designed for natural ventilation, but may suffer with inadequate internal air flow. Poor ventilation can be the result of vent blockage or due to the internal arrangement of furniture and partitions impeding air flow from not only entering the building but also from adequately ventilating all areas that need it.

Particular problems can arise in department stores due to temporary displays and signage as well as due to poorly defined air flow paths. Other public buildings suffer with stagnant areas due to no-one taking control of vents.

4.1 Cross-ventilation - partitioning/office furniture

Problems:	Solutions:
• Addition of full height partitions/cellular rooms restrict air flow. • Addition of free-standing partitions (1.4 m high and above) reduces air flow into space. • Filing cabinets and furniture may restrict air flow into space. • Arrangement of partitions/cellular rooms etc. restricts ventilation of areas. • Arrangement of department store displays, refrigeration units and ceiling hung signs can affect natural ventilation.	• A very open plan is essential; partitions, if they must be used, should be kept low, preferably under 1.2 m in height. Tall cupboards and filing systems should be placed around the perimeter wall between windows (if possible), using lower height furniture for the rest of the floor area. Otherwise, tall furniture should be placed perpendicular to the perimeter wall so as to present the least resistance to air flow into the room. Where possible remove full height partitions and reduce the size of free-standing partitions to less than 1.4 m (see page 24 Figure 7). • Cellular rooms should not be placed around the perimeter. If they are required in this position, they should have transfer grilles or windows in the internal wall to allow as much air movement across as possible, and doors should be kept open. Where possible reconfigure full height cellular rooms taking into consideration air-flows and ventilation. • Tall windows, or windows with top opening lights are effective in promoting cross ventilation at high level without inducing draughts at desk height. • Many buildings have a central corridor down their length, which, if removed, would allow air flow across the floor. If removal is not feasible then consider fitting transfer grilles. • Consider positioning displays perpendicular to air flow and carefully position signs so as to minimise the restriction to air flow.

Pitfalls to avoid

- Removing large partitions can impinge on peoples' privacy - this needs to be considered.
- It can be expensive installing grilles to aid cross ventilation, and it may pose a possible fire risk. Grilles with fire dampers may be a solution.

Case study: BSRIA's offices

This is a 795 m^2 office on three floors which is attached to laboratories. The office space is a mix of small open plan areas and cellular offices. Natural ventilation is available via manually openable sliding windows and is restricted to single sided ventilation only. Perimeter heating is also available.

In one area natural ventilation has been assisted by removing the floor-to-ceiling partitioning that formed a small cellular corner office in a larger open plan office. The marks on the walls between the two windows and by the foreground computer highlight where the old partitioning used to be. Removal of the partitioning has exposed the window to the rest of the office increasing both natural ventilation rates and natural daylight throughout the rest of the office.

Figure 4

Removal of floor-to-ceiling partitioning has increased natural ventilation

Case study: Design Studio, Open University, Milton Keynes

The open plan studio, which is about 14 m across, is cross-ventilated by provision of mid-pivot opening main windows and inward-opening hoppers forming the upper lights. Partition screens are low (typically four feet), which is enough to define spaces and provide privacy in the working areas whilst allowing free movement of air. Furniture is arranged perpendicularly to the glazed facades.

4.2 Vent blockage

Problems:	Solutions:
• Books, plants, etc. on window sills may prevent vents from opening either through physically stopping vent movement or preventing access to the opening mechanism.	• Educate occupants (see section 2.2). • Check all sills and vents for objects that impede the operation of vents. • Ensure easy access to vents and operation.
• Inlet ventilation windows open but cross ventilation restricted due to outlet vent being closed.	• Check for outlet vent being closed, if so open as appropriate.
• Curtains, blinds and items stored on window sills restrict ventilation when vent is opened, particularly where the ventilation opening is limited.	• Make sure objects are not restricting air flow. • Use interstitial blinds or external shading.
• Blinds operated to reduce solar gain are restricting air flow.	• Use interstitial blinds or external shading.

Pitfalls to avoid

- Allowing too many vents to be open on the ground floor compared to upper floors if a stack is used - the ground floor air may exhaust through windows on upper floors rather than the stack. This can result in upper floors being subjected to stale air.
- When drawing back the curtain or blind it is important that the link between lighting, blinds and solar gain is understood (see section 2.2).
- During conditions with high solar gain and relatively low internal temperature (say <24°C) it is likely to be beneficial for the blind to remain ‘closed’ providing that adequate natural light is still provided. However, as the internal temperature rises (>27°C) comfort is more likely to be improved by opening the blind to increase air flow. Individual circumstances will vary and blind operation under these conditions is probably best left to the occupant.

Case study: Office Building

This three storey building comprises mainly cellular offices and administrative areas together with some seminar spaces. The floor area is approximately 2000 m^2. Tilt and turn windows are provided to all areas.

There have been a number of issues with the vents in this building:

- *Windows in the 'turn' position can blow open and closed. They need a positioner or friction device to hold them open.*
- *Windows open in the 'turn' position impinge into the space and may present a safety hazard.*
- *Some of the rooms in this building had internal blinds fitted to allow blacking out of the room for audio visual purposes. These internal blinds interfere with the operation of the window in the turn position and restrict air flow when the window is in the tilt position (see Figure 5).*

Figure 5

Black out blinds affect window operation