BRE Digest

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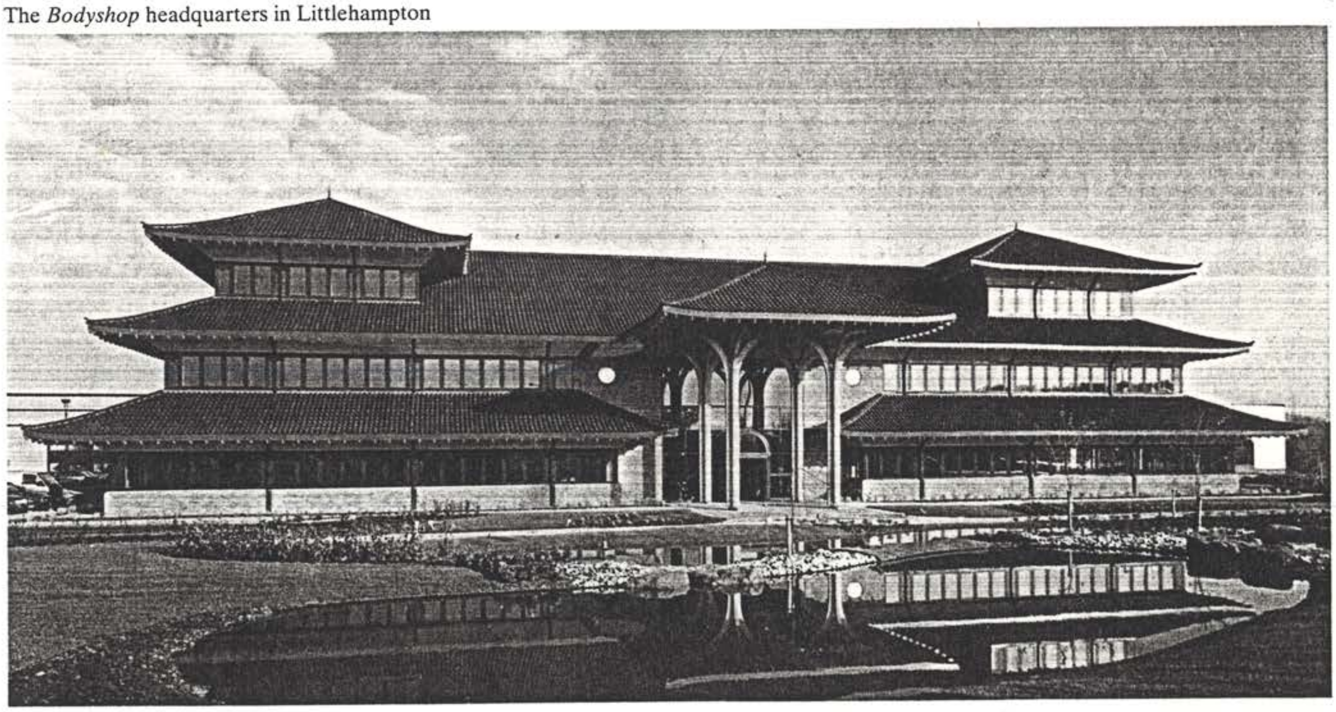
Natural ventilation in non-domestic buildings

Adequate ventilation is essential for the well being and health of building occupants and the provision of fresh air was traditionally met by natural means. This approach has partly given way to air conditioning in response to the perceived need to cool modern buildings, which tended to suffer from high solar heat gains, poor natural daylighting and use of many energy intensive appliances.

Increased concern over the adverse environmental impact of energy use has encouraged the design and construction of energy efficient buildings, many of them suited to natural ventilation. It can provide year round comfort, with good user control, at minimum capital cost and with negligible maintenance.

This Digest gives the professional design team and building users background information and design guidance on using natural ventilation in energy efficient non-domestic buildings.

The *Bodyshop* headquarters in Littlehampton



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VENTILATION REQUIREMENTS

Ventilation must provide safe, healthy and comfortable conditions for building occupants.

Fresh air is needed to:

- provide sufficient oxygen
- dilute body odours
- dilute to acceptable levels the concentration of carbon dioxide produced by occupants and combustion.

The requirement for oxygen is far smaller than that for metabolic carbon dioxide dilution. This, in turn, is less than the air needed for dilution of body odours and much less than the ventilation needed to dilute tobacco smoke and other pollutants to acceptable levels. Requirements are shown in Fig 1. Ventilation is not necessarily the preferred solution for control of other air contaminants (local extract ventilation may be more practicable).

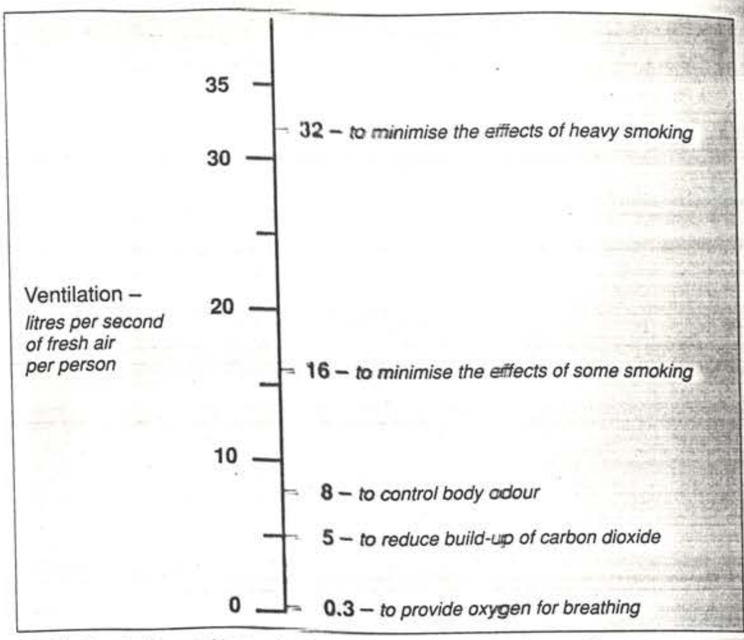


Fig 1 Fresh air requirements for a sedentary person in an office

GENERAL DESIGN GUIDANCE

Natural ventilation is defined as *ventilation driven by the natural forces of wind and temperature.* It is intentional and, ideally, controlled. It should not be confused with *infiltration,* which is the unintentional and uncontrolled entry of outdoor air through cracks and gaps in the external fabric of the building.

Depending on the circumstances, good design can provide natural ventilation for the entire building or sections of the building. Sometimes, natural ventilation can be augmented by the intermittent use of local extract fans for wet and/or polluted zones, such as photocopying rooms and kitchens.

The following basic design guidelines help to improve natural ventilation:

- shallow plan forms are better than deep ones
- shading (preferably external) minimises summer over-heating
- an airtight building envelope minimises unwanted air infiltration
- trickle ventilators (400 mm^2 openable area per m^2 of floor area) provide controllable background ventilation
- openable windows can provide controllable and draught-free ventilation but should be lockable in a secure position (for night cooling)
- allow occupants control of local ventilation
- use low-energy lighting and IT equipment to avoid unnecessary heat gains
- locate office machinery near local extract ventilation.

Figure 2 gives an indication of general limits. Detailed analytical techniques may allow more flexibility in particular cases.

Fig 2 Design parameters for natural ventilation
Typically: one occupant per 10 m^2 = 10 W/m^2
one personal computer per occupant = 10 W/m^2

Design parameters	Heat gains (including people, lighting, office equipment and solar) W/m^2			
	10	20	30	40
Impact on architectural form and finishes	Little →			Large
Suggested minimum room height – m	2.5	2.7	2.9	3.1
Easily controllable window opening (down to 10 mm)	✓	✓	✓	✓
Trickle ventilators for winter	✓	✓	✓	✓
Control of indoor air quality (could be manual)	*	*	✓	✓
Design for daylight to reduce heat gains	*	✓	✓	✓
Daylight control of artificial lighting	*	*	✓	✓
100% shading of glass from direct sun	*	✓	✓	✓
Cooling by daytime ventilation only	✓	✓	Difficult	
Cooling by night and day ventilation	✗	*	✓	✓
Internal exposed thermal mass	✗	✗	✓	✓

✓ Essential
* May be required
✗ Not necessary

MECHANISMS OF NATURAL VENTILATION

Natural ventilation is created by pressure differences between inside and outside induced by wind and temperature differences – see Figs 3 and 4.

Wind pressure on a building depends on wind direction, the shape of the building and wind speed. Temperature difference between indoors and outdoors causes density differences in the air which in turn cause pressure differences. Airflow rate through openings is not linearly related to pressure difference so, for any opening, wind-induced and stack-induced flows cannot readily be added together. The pressure generated (wind and/or temperature) is used to balance the resistance to airflow of all the openings on the air route through the building.

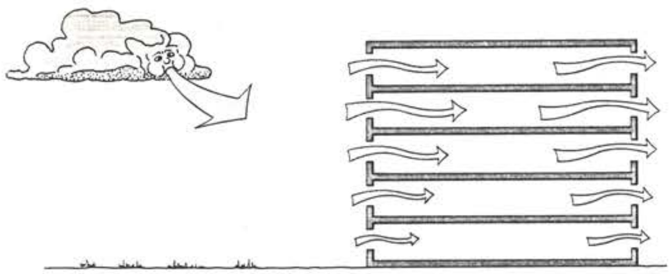


Fig 3 Wind pressure-induced natural ventilation

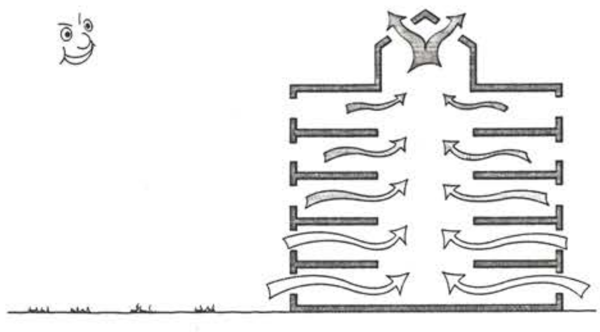


Fig 4 Temperature-induced natural ventilation

WIND EFFECT

The total wind pressure acting across a building is roughly equal to the wind velocity pressure. The mean values for buildings with different heights for a *meteorological wind speed* of, say, 4 m/s at a height of 10 m are shown in Fig 5. If the building is isolated, the full meteorological wind speed is used. In suburban areas and city centres, where the actual wind speed is lower, local winds at a height of 10 m will be reduced to 2.4 and 1.3 m/s respectively, with correspondingly reduced pressures.

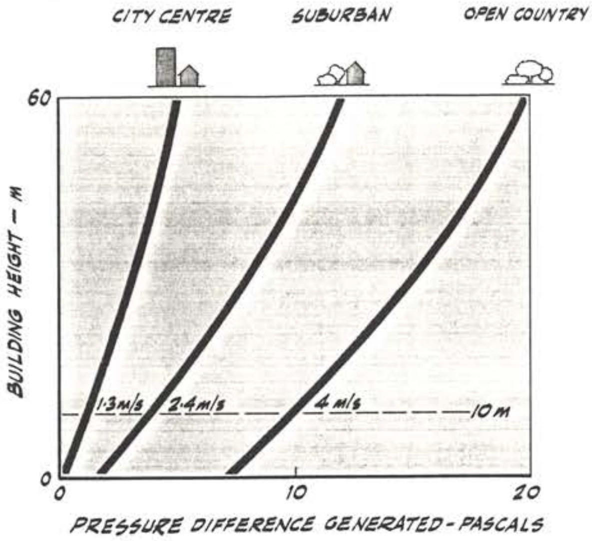


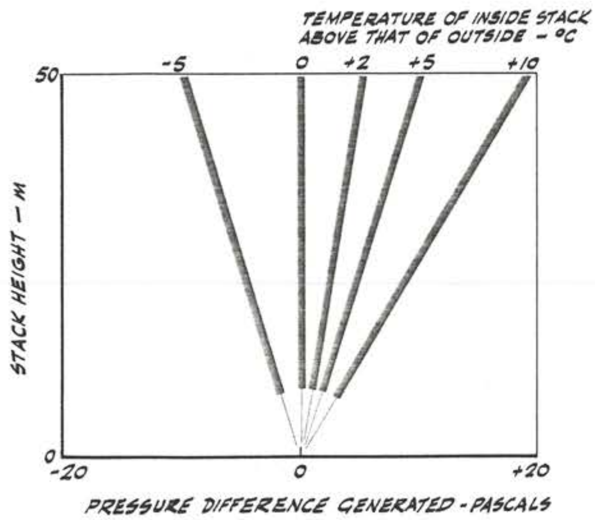
Fig 5 Wind-induced pressure generated across building for 4 m/s windspeed.
Local wind effects can result in large pressure fluctuations.

TEMPERATURE EFFECT

This is also known as *stack ventilation* and *thermal buoyancy ventilation*. A vertical pressure gradient is created by thermal buoyancy. It depends on the temperature difference between the column of warm air and the ambient temperature, and the height of the column of warm air. For each degree of temperature difference between inside and outside, a pressure difference is set up of about 0.04 Pa per metre of building height.

Figure 6 gives pressure differences due to temperature difference for a range of temperature differences and variations in height.

Fig 6 Temperature-induced pressure generated across building



DESIGN OPTIONS

Where possible, give occupants control over their local environment; this can contribute significantly to their acceptance of their environment. Consider the benefits of producing a brief and simple occupants' guide to using the building. Ventilation controls should be ergonomic and respond rapidly; explain their use to occupants.

The design of a naturally ventilated building should reflect different requirements for winter and summer occupancy. In winter, minimise excess ventilation but control background ventilation with trickle ventilators to meet occupants' needs for health. In summer, ventilation may need to exceed what is required solely to satisfy occupants' needs to avoid overheating – see Fig 2. As part of this process, the distribution of fresh air is important within the space and can enhance comfort conditions and freshness.

SINGLE-SIDED AND CROSS VENTILATION

Single-sided ventilation (Fig 7) occurs when large, natural ventilation openings (such as windows and doors) are situated on only one external wall. Exchange of air takes place by wind turbulence, by outward openings interacting with the local external airstreams and by local stack effects.

Cross ventilation (Fig 8) occurs when inflow and outflow openings in external walls have a clear internal flow path between them. Flow characteristics are determined by the combined effect of wind and temperature difference. Cross ventilation depends on windows (or other openings) on opposite sides of the building being opened sufficiently; this needs the co-operation of occupants. The effectiveness of ventilation in deep spaces can be affected by internal partitions and obstacles. This generally affects only air movement which can then be increased locally, by ceiling fans for example.

CIBSE Guide A [1] and BS 5925 give simple equations to estimate single-sided and cross ventilation flows. The rules of thumb shown in Figs 7 and 8 apply for moderate to high heat gains. If heat gains are lower, recent BRE research indicates that deeper spaces can be ventilated naturally [2].

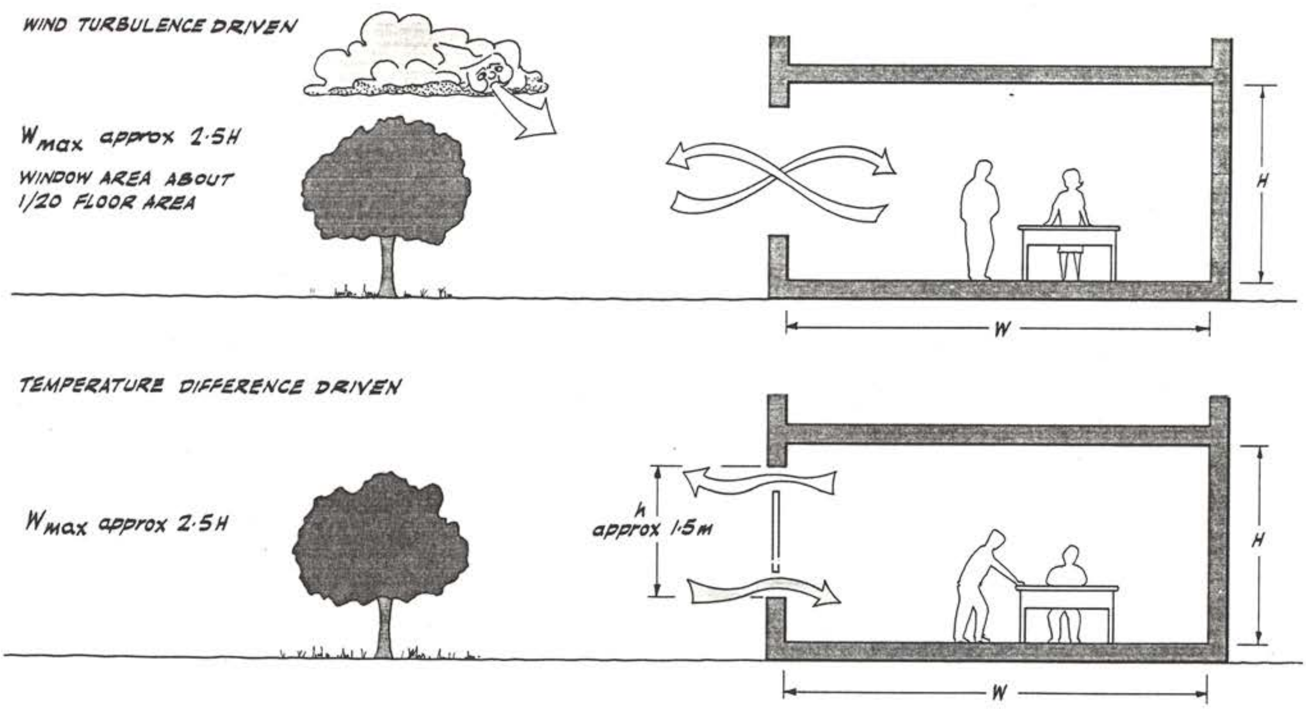
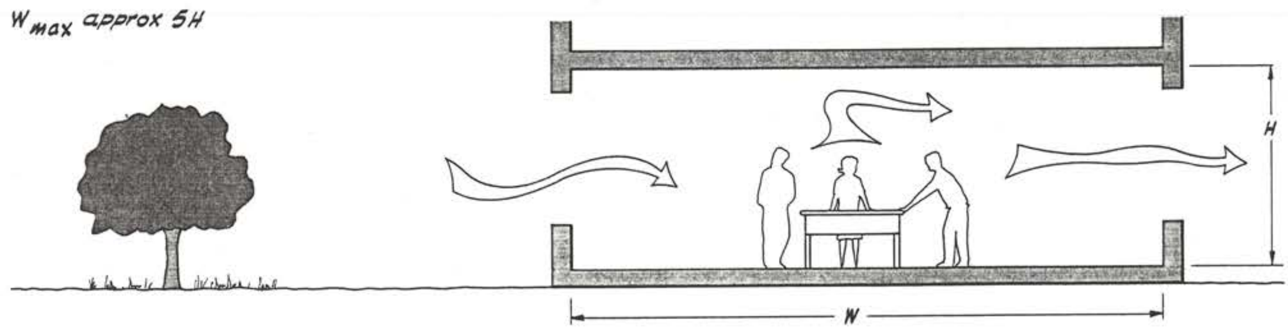


Fig 7 Single-sided ventilation

Fig 8 Cross ventilation



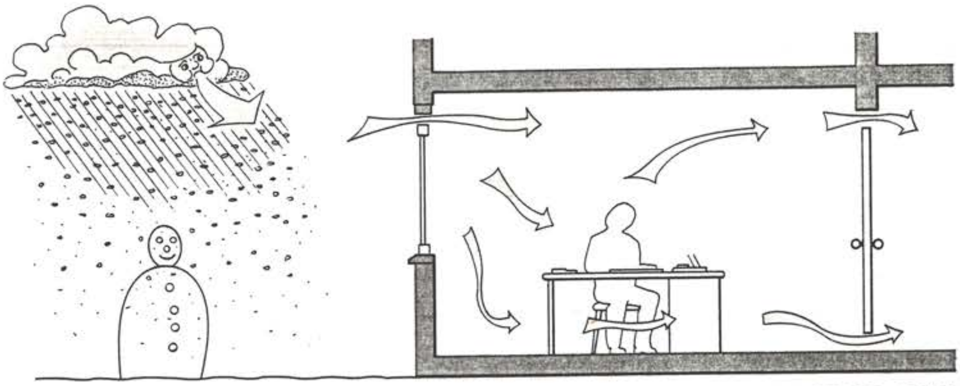
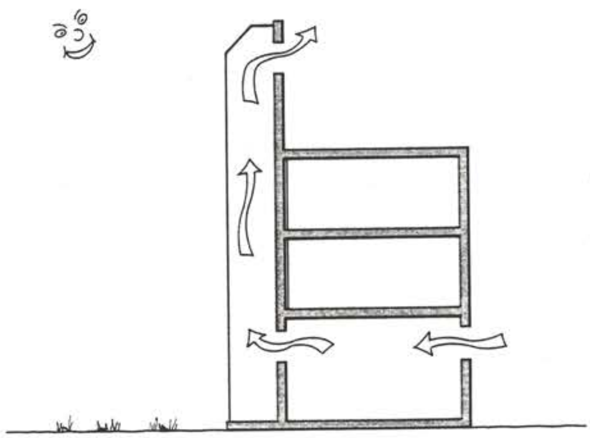


Fig 9 Trickle ventilators could provide required fresh air in winter

BACKGROUND VENTILATION
In winter, ventilators with an openable area of 400 mm^2 per m^2 of floor area can usually provide adequate background ventilation in multi-celled buildings. Controllable trickle ventilators can be a very effective way of doing this – see Fig 9.



STACK VENTILATION
Passive stack elements can take the form of solar chimneys which create a column of air at higher-temperature. This generates higher pressure differences and so further enhances the stack effect – see Fig 10. Passive stack can also be promoted through an atrium which will additionally act as a buffer to reduce fabric heat losses.

Fig 10 Solar chimney principle

ISSUES INFLUENCING DESIGN OPTIONS

SITE CHARACTERISTICS
Green field sites pose fewest problems for natural ventilation. In urban sites, noise and external air pollution can be reduced by appropriate window design and location of office space.

Buildings in areas of severe exposure, for example on hills and coastal sites, generally need smaller or fewer ventilation openings than those that are sheltered. Shelter belts (plantings of trees and shrubs to act as wind breaks) are usually placed perpendicular to the direction of the prevailing wind. The resistance depends on the density of the foliage and is greatest immediately behind the shelter belt. Artificial wind breaks can provide shelter. Ventilation design for low-rise buildings near tall buildings should consider the effect of higher wind speeds at ground level as well as changes in wind induced pressures on the building facade – see Fig 11.

HEATING SEASON
Minimise heat losses and draughts due to uncontrolled air infiltration by ensuring that all external openings are weather-stripped and, if possible, by making the building envelope airtight. Provide draught-lobbies to frequently-used external doors and shelter them from prevailing winds. Minimise local radiant heat loss and down-draughts from large areas of glass by using double or triple glazing, insulated blinds and low-level heating.

SUMMER OVERHEATING
It should be accepted that internal conditions affecting comfort vary with time in naturally ventilated buildings. However, it should be possible to maintain a comfortable range of conditions, without resorting to the provision of artificial cooling, by using such measures as shade, thermal mass, air movement, lighting controls, low-energy lighting and IT equipment.

Cross-ventilation through openable windows should generally provide these flow rates in conventional shallow-plan buildings. However, there will be cases where natural ventilation will not be satisfactory.

Ventilation can be used during the night to cool the building structure and so limit the temperature rise during the following day. The effectiveness of night-time ventilation for cooling depends on the difference between the ambient temperature and the internal temperature as well as on the thermal characteristics of the building – see Fig 12.

WINDOWS

A window is the most obvious controllable opening for natural ventilation, especially in summer. The 1995 edition of Building Regulations Approved Document Part F (Ventilation) recommends an openable area of at least 1/20th of the floor for rapid ventilation.

Windows should:

- ventilate effectively (Fig 13) but not cause draughts
- provide sufficient glare-free daylight and adequate view out of the building
- keep out excessive solar gain
- provide good insulation and avoid condensation
- allow occupants to adjust finely the openable area
- be simple to operate.

There can be a conflict between security and good ventilation. Large, open windows can present a security risk, especially on the ground floor. However, by adopting particular window opening designs, or by separating the ventilation element from the window, natural ventilation can be provided without compromising security. This is particularly important for night ventilation. Windows may have to provide good sound insulation and this may influence their ventilation effectiveness.

INTERNAL AIR MOVEMENT

For openable windows, the maximum achievable air velocity in inner areas is determined by the distance from an open window and by the degree of obstruction in the air path. Occupants near windows will usually have control of the window opening and may tend to open the window to suit only their own comfort.

In winter, the maximum acceptable level of air movement is limited to about 0.8 m/s by cold draughts, sensation of excessive cooling, and by the point at which papers on desks start to be disturbed.

In summer, it is best to use desk or ceiling fans to provide local air movement.

Fig 12 Ventilate at night to restrict temperature rise next day

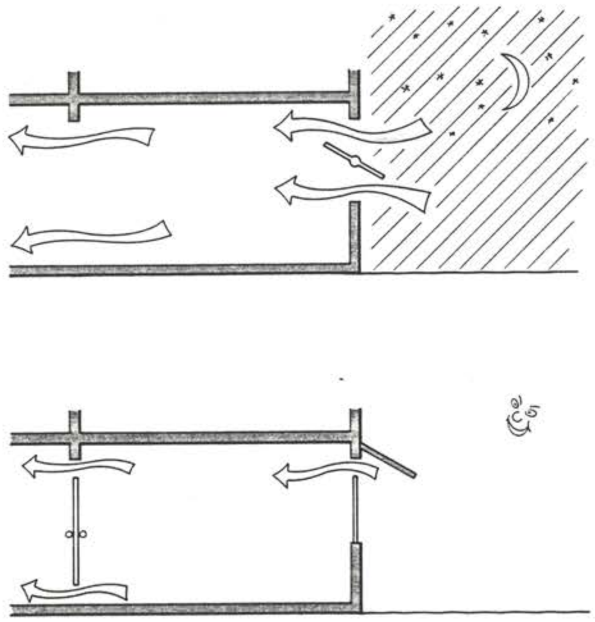


Fig 11 A tall building can deflect high speed winds down to ground level and affect the pressure distribution on a nearby low-rise building. This could change, or even reverse, the ventilation flow through the low-rise building. The actual pressures depend on wind direction and the height and spacing of buildings. *It is pressure differences, rather than absolute pressure, that drive flows.*

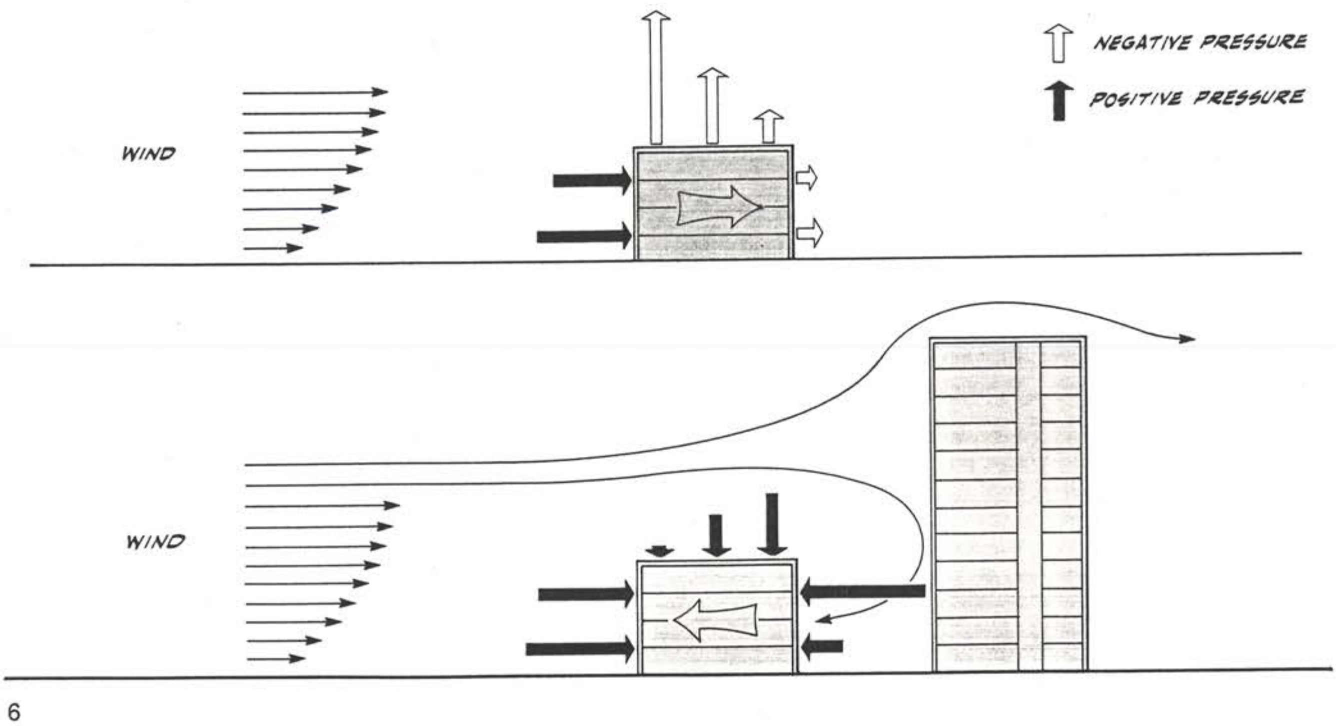


Fig 13 Effect of window shape

INTERNAL POLLUTANTS

A common misconception is that dilution ventilation is the only way to remove harmful contaminants from within the occupied space. The Health and Safety Executive (HSE) gives guidelines [3] for acceptable concentration limits for most common pollutants in the work-place. However, dilution ventilation to reduce or eliminate these contaminants to levels below these guidelines may not be better or more economical than other methods.

The UK COSHH Regulations [4] lists the following methods (in order of preference) to ensure maintenance of good indoor air quality:

- eliminate the substance
- substitute the substance by another less hazardous
- enclose the process
- partially enclose the process and provide local extract ventilation
- provide general (dilution) ventilation.
- provide personal protection.

Tobacco smoking is an avoidable contaminant and buildings can have either a no-smoking policy or separate, ventilated smoking rooms. If these are not possible, the following fresh air requirements, in litres per second, are recommended for each occupant:

- light smoking (25% of occupants smoking): 16
- heavy smoking (45% of occupants smoking): 24
- very heavy smoking (70% of occupants smoking): 32

DESIGN TOOLS

The guidance in this Digest applies to most buildings in the UK. However, there may be cases where the guidance is too simplistic or where the building does not satisfy criteria such as depth, occupancy profiles or low internal heat gains. With these, advanced natural ventilation design features must be used. Designing for natural ventilation is not a soft option; designers may need to use more ingenuity in producing a suitable design. One spin-off from this could be greater variety and more interesting buildings, as solutions are sought for techniques for promoting and controlling natural ventilation through the building. Examples are the depth of the building through changes to its footprint, using building features such as atria, courtyards, ventilation shafts, and by attention to the distribution and shape of ventilation openings.

There are many tools to help the designer; they include numerical predictive techniques, such as single-cell and multi-cell computer models, and computational fluid dynamics (CFD) models.

A novel development to assess buoyancy-driven flows within large enclosures is the salt bath technique [4].

REFERENCES AND FURTHER READING

1 **Chartered Institution of Building Services Engineers.** Guide A1. Environmental criteria for design. 1978, London, CIBSE, reprinted 1986.

2 **Walker, RR and White, MK.** Single-sided natural ventilation: how deep an office? *Building Serv Eng Res Technol,* 13 (4), 231 – 236, 1992.

3 **Health and Safety Executive.** Ventilation of the workplace EH22 (Rev), HMSO, 1988.

4 Control of substances hazardous to health Regulation 1988. Approved code of practice. HMSO.

5 Salt solution. *Building*, 1 June, 1990.

Building Research Establishment
Environmental design manual: summer conditions in naturally ventilated offices. BRE Report BR 86. Garston, BRE, 1988.

Other BRE Digests
309 Estimating daylight in buildings. Part 1
310 Estimating daylight in buildings. Part 2
346 The assessment of wind loads *(in eight parts)*
350 Climate and site development *(in three parts)*
390 Wind around tall buildings

British Standards Institution
BS 5925: 1991 Code of practice for ventilation principles and designing for natural ventilation

BRE acknowledges assistance in the preparation of this Digest by the members of the CIBSE Natural Ventilation Group and, in particular, the following ad hoc task group:

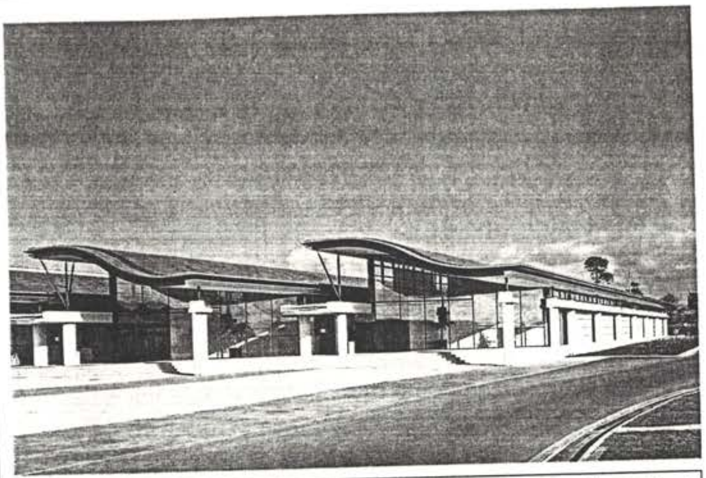
Peter Willan: Willan Building Services
Martin Liddament: AIVC
Phil Dolley: ETSU
Andrew Burke: DoE
Earle Perera: BRE
Maria Kolokotroni: BRE

We are grateful also to Chris Twinn of Ove Arup and Partners for providing the rules of thumb for Fig 2 and for the basis of some of the illustrations.

CASE STUDIES

Classrooms at The Cable & Wireless College in Coventry are so designed that buoyancy forces will provide natural ventilation (with heat gains of up to 50 W/m^2) when no cross-ventilating wind pressure is available. The buildings have a distinctive wave-form roof to provide the necessary height differential between inlet and outlet for the ventilation requirements of the 9 m-deep teaching rooms – *photo right.*

Architects: McCormac Jamieson Prichard
Environmental Engineers: Ove Arup and Partners
Photo: Ove Arup and Partners



The Learning Resources Centre at Anglia Polytechnic University in Chelmsford is a 6000 m^2 atrium stack-driven, naturally-ventilated library/computer building. It is 30 m deep, and uses heavyweight exposed thermal mass for cooling and lightshelves for extended daylighting. Due for completion during 1994, it will be extensively monitored.

Architects: ECD
Environmental Engineers: Ove Arup and Partners

The headquarters of Bodyshop in Littlehampton provides natural ventilation via triple-glazed openable windows. The offices are on three floors and are arranged around a central courtyard. Laboratory areas on the deep ground floor are mechanically ventilated because of the risk of dust – *Photo page 1.*

Architects: Michael Cook Associates

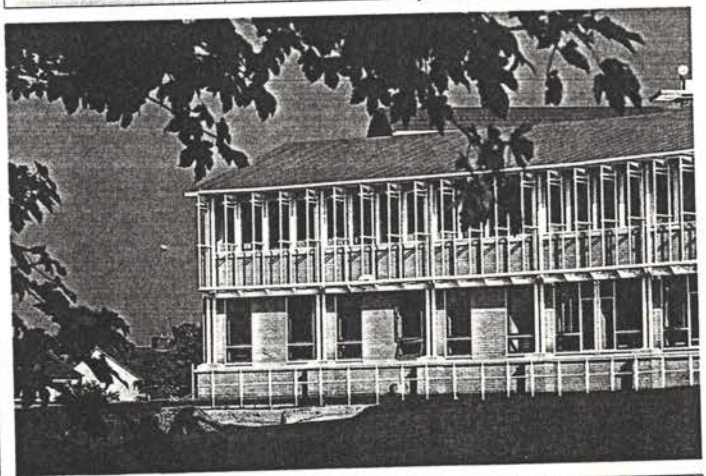
Two recent well-known examples of naturally ventilated buildings are:

The School of Engineering at DeMontfort University
Architects: Ford Short
Environmental Engineers: Max Fordham and Partners

Inland Revenue building in Nottingham
Architects: Michael Hopkins
Environmental Engineers: Ove Arup and Partners

The two-storey John Cabot City Technology College in Bristol uses cross ventilation in all the teaching areas. In the 8000 m^2 building, the ground floor classrooms are cross ventilated using rising exhaust chimneys at the rear of the rooms; the first floor uses the rising pitch of the roof to give the necessary height differential between inlet and outlets – *photo below.*

Architects: Fleiden Clegg
Environmental Engineers: Buro Happold



The following three buildings have worked reasonably well for 10 years and have provided valuable design feedback.

The BRE Low-energy office is a narrow-plan, three-storey cellular building. Originally designed for mechanical ventilation with heat recovery, it was later converted to natural ventilation through openable windows.

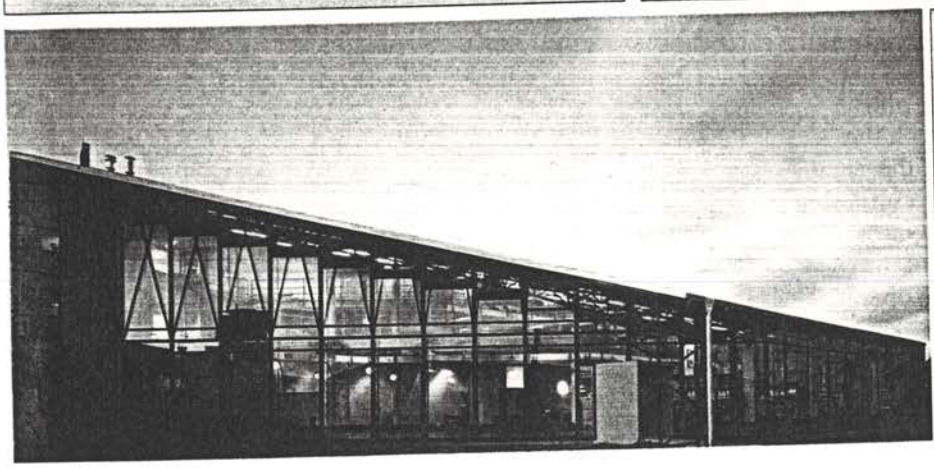
Architects: PSA
Environmental Engineers: BRE

The Gateway 2 building in Basingstoke incorporates an atrium for natural ventilation. The double-glazed roof lights can be opened and the stack effect induces air movement through the building via the perimeter windows.

Architects and engineers: Arup Associates

The South Staffordshire Water Company building has naturally ventilated perimeter offices through openable windows. The kitchens and toilets, located in the core of the building, are mechanically ventilated.

Architects: Harry Bloomer Partnership
Energy consultants: Databuild



Openable windows provide natural ventilation in the Atlantis Paper Company building in East London. Hot air inside the building rises naturally to the apex of the roof at the back of the building where a fan exhausts the air to the outside. Combined with the building's orientation, the over-sailing monopitch roof provides shading to limit summer sun penetration. Temperature sensors inside trigger an automatic two-stage increase in ventilation rate – *photo left.*

Architects: Paul Hyett Architects
Environmental engineers: Max Fordham and Partners
Photo: Joss Reiver Bany

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