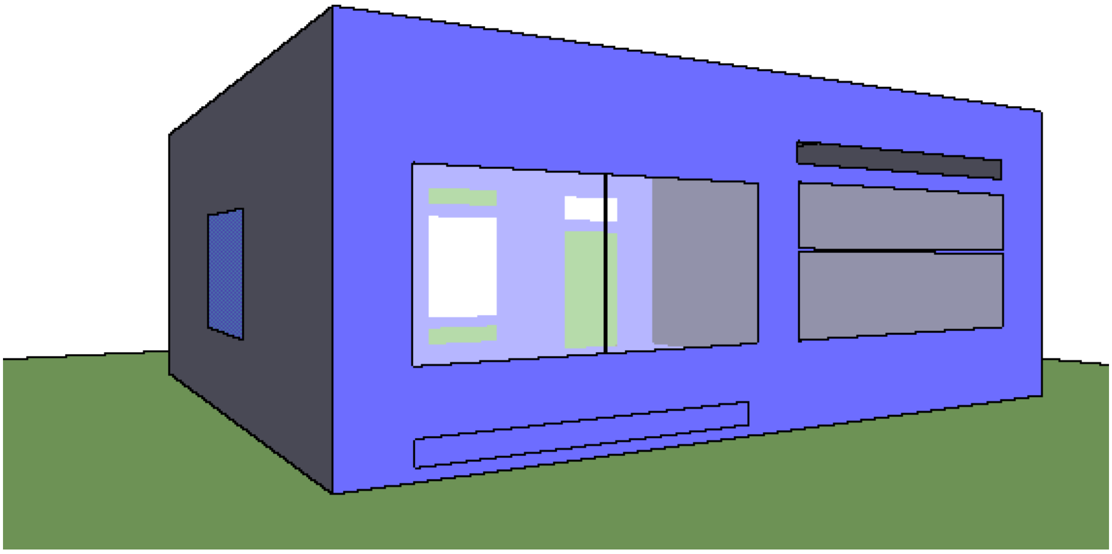
Building Bulletin 101
Ventilation of School Buildings



Regulations
Standards
Design Guidance

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1 Regulations for School Buildings

1.1 Introduction

This Building Bulletin on ventilation provides the regulatory framework for the design of ventilation in schools in support of the Building Regulations. It deals with the design of school buildings to meet the ventilation requirements as determined by both The School Premises Regulations[1] and the Building Regulations Part F (Ventilation)[2]. This Building Bulletin is quoted in Approved Document F as a means of compliance with Regulation F1 of the Building Regulations for school buildings. The performance standards for ventilation for new school buildings, as given in section 1 of this building bulletin, are required to be achieved under the Building Regulations.

1.2 Part F of the Building Regulations

Part F of the Building Regulations, as mentioned above, is an inclusive regulation that covers all buildings including schools. The Requirement F1, from Part F of Schedule 1 to The Building Regulations 2000, states:

> *"Requirement F1: There shall be adequate means of ventilation provided for people in the building."*

The requirements of Part F are performance based supported with guidance contained within Approved Document F. Approved Document F states:

> *"In the Secretary of State's view the Requirement of Part F will be met where a ventilation system is provided which under normal conditions is capable (if used) of restricting the accumulation of such moisture (which could lead to mould growth) and pollutants originating within a building as would otherwise become a hazard to the health of the people in the building."*
>
> *In general terms the requirement could be achieved by providing ventilation to:*
>
> *a. extract, before it is generally widespread, water vapour from areas where it is produced in significant quantities (e.g. kitchens, utility rooms and bathrooms);*
>
> *b. extract, before they are generally widespread, pollutants which are a hazard to health, from areas where they are produced in significant quantities (e.g. rooms containing processes or activities which generate harmful contaminants);*
>
> *c. rapidly dilute when necessary, pollutants and water vapour produced in habitable rooms, occupiable rooms and sanitary accommodation;*
>
> *d. make available over long periods a minimum supply of outdoor air for occupants and to disperse where necessary, residual pollutants and water vapour. Such ventilation should minimise draughts and where necessary, should be reasonably secure and provide protection against rain penetration.*
>
> *Mechanical ventilation proposed for buildings would satisfy the requirement if it provides, as appropriate, ventilation equivalent to that set out in (a) to (d) above and is:*
>
> *e. designed, installed and commissioned to perform in a way which is not detrimental to the health of the people in the building; and*
>
> *f. installed to facilitate necessary maintenance including cleaning of ductwork.*

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1 The Schools Premises Regulations apply to existing buildings and currently contain requirements for ventilation rates in school buildings. The recommendations given in the following pages constitute the requirements for future schools and the SPR will be amended in line with these recommendations.

2 Review of Approved Document F – Ventilation A consultation package July 2004. ODPM

1.3 Performance Based Standards

Approved Document F, and this compliance section of Building Bulletin 101, focuses on performance based guidance. Approved Document Part F sets out the following levels of moisture and other pollutants for buildings other than dwellings, based on office type accommodation.

- The average relative humidity in a room should not exceed 70% for more than two hours in any twelve hour period during the heating season.
- Nitrogen dioxide (NO_2) levels should not exceed 288 $\mu g/m^3$ (150 ppb) averaged over one hour.[3]
- Carbon monoxide should not exceed
    - 100 mg/m^3 (90 ppm) – 15 minute averaging time
    - 60 mg/m^3 (50 ppm) – 30 minute averaging time
    - 30 mg/m^3 (25 ppm) – 1 hour averaging time
    - 10 mg/m^3 (10 ppm) – 8 hours averaging time
- Total volatile organic compound (TVOC) levels should not exceed 300 $\mu g/m^3$ averaged over eight hours.
- Ozone levels should not exceed 100 $\mu g/m^3$.

1.4 Ventilation Performance Standards for Schools

The performance standard for school buildings, partly for historical reasons, is based on the requirement to control the carbon dioxide that results from the respiration of occupants. This is the key indicator of ventilation performance for the control of indoor air quality. Therefore compliance in schools requires the performance standards required under Part F of the Building Regulations to be met as well as the additional requirement that:

The concentration of carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day should not exceed 1500ppm 1]*. The whole day refers to normal school hours (i.e. 9.00am to 3.30pm) and includes unoccupied periods such as lunch breaks.*

[3] Department of Environment, 1996 source

1.5 Ventilation Provision

The following specifies levels of ventilation that if achieved would in normal circumstances comply with the required CO_2 performance standard. The designer has the freedom to use whatever ventilation provisions suit a particular building, including the use of innovative products and solutions, if it can be demonstrated that they meet the performance standards recommended in this document. However, to satisfy the performance standard the following categories of ventilation are provided for guidance:

1.5.1 Minimum Fresh Air Supply Rate

The minimum supply of external air shall not be less than 3l/s per person in all teaching and learning spaces when they are occupied. This category of ventilation may be seen as analogous to the **'whole building'** as discussed in Part F and must be provided based on the maximum number of occupants likely to occupy the space.

1.5.2 Design Capability

In addition to the requirement for a minimum fresh air supply rate of 3l/s per person, all teaching and learning accommodation shall be capable of being ventilated at a minimum of 8l/s per person for the normal number of occupants. This is the **'purpose provided'** ventilation that may not be required at all times of occupancy but, as with the minimum rate, it is a key requirement that it should be achievable under the control of the occupant. The design capability should be available for typical weather and operating conditions of the school. It must be pointed out that this 'purpose provided' ventilation may not rely solely on window usage but could also include other ventilation paths such as louvres or stacks.

The **capability** of achieving this rate of external air supply is important, rather than maintaining this level of ventilation continuously. When fresh air of 8l/s/per person is supplied the carbon dioxide concentration will generally remain below 1000ppm. This 8l/s/per person capability must be provided at all occupied times if a mechanical ventilation system is specified.

1.5.3 Daily Average Fresh Air Supply

Although not stated in the Schools Premises Regulations, the HSE standards for workplaces require that external air is provided at 5l/s per person[4] - considering that this rate is sufficient for supplying a suitable volume of fresh air for the occupants and to remove background pollutants from other sources.

For school classrooms a daily average fresh air supply rate (for the period covering the normal occupied day of 09:00 to 15:30) of 5l/s per person is also considered as suitable. At times the rate might be below this but this average should be attainable in a controllable manner.

For office accommodation, in the absence of tobacco smoke or other excessive pollutants, a supply rate of 10l/s per person is recommended. This outdoor air supply rate is based on controlling body odours with low levels of other pollutants. However, ADF acknowledges that this rate may not be adequate to address pollutants from occasional, occupant-controlled events such as painting, smoking, cleaning or other high-polluting events.

4 EH22 HSE Workplace (Health, Safety and Welfare) Regulations 1992 - Guidance for the Education Sector. See http://www.hse.gov.uk/pubns/iacl97.htm#1

1.6 Acoustic Standards- Designing to meet the BB93 indoor ambient noise levels at the minimum and design capability fresh air supply rates.

It is recognised that schools should be naturally ventilated and required to meet the acoustic performance standards defined by BB93. Since the publication of BB93, interim guidance for meeting the indoor ambient noise levels at specified ventilation rates was available at www.teachernet.gov.uk/acoustics. The text below provides a clarification of the guidance in BB93:

For the Minimum Fresh Air Supply Rate of 3 l/s per person the design should achieve the BB93 performance standards for the indoor ambient noise levels in Table 1.1 of BB93. If the design uses a Minimum Fresh Air Supply Rate that is greater than 3 l/s per person, the indoor ambient noise levels with this ventilation rate should still achieve the BB93 performance standards in Table 1.1 of BB93[5]*.*

When the Design Capability Supply Rate of 8 l/s per person is provided by natural ventilation the design should achieve the BB93 performance standards for the indoor ambient noise levels in Table 1.1 of BB93 when they have been increased by 5dB $L_{Aeq,30min}$.

The only exceptions to this requirement, at all fresh air supply rates, are classrooms designed specifically for use by hearing impaired students and speech therapy rooms.

All mechanical ventilation systems must meet the indoor ambient noise levels in Table 1.1 of BB93.

This means that a natural ventilation strategy meeting the BB93[6] indoor ambient noise level requirements should be attainable; there is flexibility for lower noise levels during occupied periods and ventilation at a rate of 3l/s per person and the higher permissible levels at a higher ventilation rate of 8 l/s per person. In addition when the classroom is unoccupied higher noise levels may be acceptable to provide rapid purge ventilation.

1.7 Applicability of Regulations

The Building Regulations, The School Premises Regulations and hence the requirements of this Building Bulletin apply only in England and Wales. This Building Bulletin applies to LEA maintained schools and independent schools. The Building Regulations also apply to other educational buildings.

Temporary buildings are exempt from the Building Regulations but not from the School Premises Regulations. Temporary buildings are defined in Schedule 2 to the Building Regulations as those which are not intended to remain in place for longer than 28 days. In the context of schools, temporary buildings are normally classed as prefabricated buildings and are therefore subject to the Building Regulations.

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5 BB93 contains recommendations on demonstrating compliance to the client using acoustic testing. The guidance on testing in clauses 1.3.3 and 1.3.4 state that during measurements the ventilators or windows used for natural ventilation should be open as required to provide adequate ventilation. For consistency with this Building Bulletin, the updated guidance is that during measurements the ventilators or windows used for natural ventilation should be open as required to provide the Minimum Fresh Air Supply Rate.

6 Building Bulletin 93, (Part E4 of Building Regulations 2000, 2003 Edition BB93).

See http://www.teachernet.gov.uk/management/resourcesfinanceandbuilding/schoolbuildings/designguidance/sbenvironmentalhs/acoustics/

1.8 Work On Existing Buildings

When a building undergoes a Material Change of Use[7], Part F applies to the building, or that part of the building, which has been subject to the change of use. Therefore, the guidance in this document applies.

Although it would be uneconomic to upgrade all existing school buildings to the same standards as new school buildings, where the ventilation performance of an existing building needs to be upgraded or when the building is being refurbished for other reasons, the designer should aim to meet the requirements of BB 101 and school designs must comply with the School Premises Regulations.

Windows are a controlled fitting of the Building Regulations and therefore when widows in an existing building are replaced, the work should comply with the requirements of Parts L and N. Also the building work should not have a worse compliance, after the work, with other applicable Parts of schedule 1. These include Parts B, F and J.

Where the original windows included trickle ventilators the replacement windows should make allowance for this by providing an equivalent controllable ventilation opening of an area no smaller than the original.

7 As defined in regulations 5 and 6 of the Building Regulations 2000 (as amended)

2 Ventilation of special areas or buildings

In addition to the general requirements set out above for teaching and learning spaces there are a number of other specialist areas in schools for which the ventilation requirements need particular consideration. Some of these are dealt with in the following sections.

2.1 Practical spaces

The ventilation of all practical spaces, such as art and design and technology areas, must, in the first place, be designed to provide adequate ventilation for the occupants according to the requirements. However, in addition, it should also prevent the build-up of unwanted pollutants. In practice, general ventilation can be provided - that is the whole space may be ventilated to prevent the build-up of pollutants, or local exhaust ventilation can be provided to deal with a specific process or pollutant source such as dust or fumes that pose a risk to the health and safety of users or affect their comfort.

Local exhaust ventilation may be necessary following a risk assessment carried out under the Control of Substances Hazardous to Health Regulations 2002 and typical situations where local exhaust ventilation may be needed are as follows (taken from BS 4163).

- Cooking appliances that give off steam, oil, grease, odour, and heat and products of combustion;
- Equipment for heat treatment, including for brazing, forging, welding, and soldering;
- Woodworking machines, including for sawing, sanding, planing, and thicknessing;
- Chemical processes, including acid pickling, plastics work, paint spraying, and engine exhaust emissions;
- Working with adhesives;
- Metalworking machines (grinding and polishing) and
- Working with plastics and glass reinforced plastics (GRP).

Fume cupboards may be needed in some labs and prep rooms. Other important points to consider are listed below:

- Combustible dusts (e.g. fine particles of wood, plastics and some metal dusts) should be separated from those produced in processes where sparks are generated.
- The local exhaust inlet should be sited as close as possible to the source of contaminant. and extracted to a place which will not cause harm
- It is essential that air is brought into the space to compensate for air exhausted to the outside. (NB make-up air may need to be heated in order to maintain adequate internal conditions).

CAM machines require their own extraction systems. Both the machine and the extract system can be very noisy and since they are often left running during other class activities this can cause disturbance. Sometimes the problems associated with local extracts can be dealt with by a remote extract fan and associated filtration - this removes noise and also is more space efficient.

The Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS)[8] produces risk assessments for pollutants commonly used in science and design technology. The CLEAPSS 'hazcards' specify a 'well ventilated room' for science labs. The CLEAPSS Model Risk Assessments for Design and Technology define ventilation needs for many design and technology processes. The CLEAPSS requirement for a "well ventilated room" may also indicate a need for local extract, or exhaust ventilation over the work bench in extreme cases. For example a cooker hood may be needed over a hob or a fume hood or fume cupboard for handling chemicals.

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[8] http://www.cleapss.org.uk/

Ventilation systems specifically installed to remove hazards (e.g. fume extractor) and fans should not be controlled by emergency stop systems fitted in Design Technology spaces to isolate electrical circuits in the event of accidents.

The following documents provide useful guidance on local exhaust ventilation and refer to further information sources:

- HS(G) 37 Local Exhaust Ventilation.
- HS(G) 54 Maintenance, Examination and Testing of Local Exhaust Ventilation.
- HS(G) 193 COSHH Essentials (accessed on www.coshh-essentials.org.uk)
- Industrial Ventilation 24th Edition, Manual of Recommended Practice, American Conference of Government Industrial Hygienists.
- BS 4163 Health and safety for design and technology in schools and similar establishments Code of practice (AMD 11025).

2.2 Information Technology (IT) suites

Natural ventilation should be used for standard teaching zones with limited computer equipment. BB87 suggests that up to five desktop PCs with CRT screens, a laser printer and an OHP/computer projector will constitute the ICT equipment in a 'typical' classroom. Above this threshold, additional ICT equipment should be considered as a process load and treated as such in interpretation of the Approved Document. These internal gains, which provide useful heat in the heating season, can lead to overheating in the summer and therefore should be reduced as much as possible by selection of efficient appliances with low heat rejection. If less efficient equipment is used then other elements of the building must be improved to compensate for the increased equipment loads.

In areas with high levels of ICT i.e. above the basic provision of five PCs and a laser printer and OHP/computer projector – then mechanical ventilation and comfort cooling may be considered providing other passive means of maintaining thermal comfort have been thoroughly investigated.

It may be possible to avoid overheating of ICT suites through good natural ventilation system design with medium weight construction and measures to minimise solar gains. With an appropriate control strategy, for most of the year, mechanical ventilation may not be needed.

The building regulations F1 requirement for computer rooms can be met by following the guidance in CIBSE B2: 2001, Section 3.9.

2.3 Food Technology

Only teaching areas are covered here. Some form of mechanical ventilation will be required in most food preparation areas at least some of the time to deal with the heat gain and water vapour produced by cooking and other equipment and solar gains. Cookers in food rooms will need adequate extraction. This may be in the form of individual extraction hoods although these are noisy. Mixed-mode mechanical/natural ventilation systems rather than full mechanical ventilation systems will probably be the most economic solution. Heat recovery on local extract fans and on supply and extract systems may be helpful in winter to minimise ventilation heat losses. However, there will be a need for by-pass or separate arrangements for summer ventilation. Cleaning of grease from any heat recovery systems must be considered during design. Specialist advice may be required.

Food rooms should ideally be enclosed in order to prevent dust from contaminating food. Opening windows may need fly guards to prevent insect contamination. If refrigerators or freezers are kept in storerooms ventilation must be sufficient to maintain cool general conditions.

For guidance on ventilating catering kitchens see:

- HSE Catering Information Sheet No 10, 2000.
- HSE Information Sheet No 11, 2000.

- CIBSE Guide B2: 2001, Section 3.6

2.4 Hot metal equipment

Where provision has to be made for hot metal work then local exhaust ventilation for fumes should be provided for all equipment, as indicated in 1.1 above. Additionally, where the heat source is provided by gas, a gas solenoid protection should be provided in the main gas supply in case an electricity failure disrupts the air supply.

2.5 Science labs, prep rooms and chemical store rooms.

Ventilation will be required for pollutant loads from chemical experiments, heat gains from Bunsen burners and other equipment and solar gains. Carbon dioxide is also generated from the use of Bunsen burners; in a class of 30 pupils, CO_2 from Bunsen burners can be more than twice as high as that from respiration.

Local exhaust ventilation is usually required in science laboratories where chemical experiments are conducted. This allows for the possibility that 30 pupils might conduct chemical experiments at any given time. Where natural ventilation cannot be relied upon to provide the necessary ventilation, mechanical ventilation might be needed. Heat recovery on local extract fans and on supply and extract systems is recommended to minimise ventilation heat losses. Partially opening windows are useful for natural ventilation when chemical experiments are not being conducted. Fume cupboards should be installed and operated correctly. Further information can be found in BB88 – Fume Cupboards in Schools (1998) The Stationery Office, ISBN 0-11-271027-1.

However, problems from emissions and heat gains are likely to be intermittent rather than continuous so some form of boost ventilation is the preferred option. The CLEAPSS risk assessments for pollutants (including carbon dioxide) generated by science experiments conducted in a typical open laboratory assume 5 air changes per hour. If the ceiling height is low then a higher ventilation rate is needed.

The supply of incoming air must be adequate to compensate for extraction when ducted fume cupboards are in use. The extracted air should be discharged at a minimum height of one metre above the highest part of the building. All fume cupboards in schools should be installed and used according to the guidelines laid down in Building Bulletin 88 ‘Fume Cupboards in Schools’[9].

Prep rooms tend to adjoin science labs and suffer from inadequate ventilation. Often they are used to store chemicals, but regardless of this CLEAPSS suggest a ventilation rate of 5ach should be adequate.

Chemicals should preferably be stored in a dedicated chemical store room. As these are not occupied for significant lengths of time a ventilation rate of 2ach should suffice. Store rooms with well-sealed fire doors can preclude inward make-up air to replace exhausted air. This problem may also arise to a lesser extent with modern laboratories and prep rooms with highly sealed windows. Pathways for make-up air, and the location of intakes in relation to outlets, therefore need to be considered carefully. It is sometimes possible to fit grilles even in fire doors.

The F1 requirement for laboratories can be met by following the guidance in CIBSE Guide B2: 2001, Section 3.16

2.6 Swimming pools

Ventilation is the major determinant of comfort conditions in swimming pools as they are subject to high rates of evaporation. Careful design of the heating and ventilation by an experienced engineer is essential to maintain the desired temperature and humidity conditions. The ventilation strategy needs to consider the fabric construction, its thermal conductivity (U-values) and permeability to

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9 Building Bulletin 88 ‘Fume Cupboards in Schools

water vapour. Calculated predictions of interstitial condensation will be needed to match the ventilation to the fabric performance.

2.6.1 Design standards

Ventilation serves two purposes; to remove contaminants from the atmosphere within the pool hall and; to control the air quality, temperature and humidity to ensure user comfort. To achieve these objectives warm air has to be distributed evenly throughout the enclosure at flow rates that are within acceptable limits for bather comfort.

The comfort of the wet bather is very dependent on the conditions. Relative humidity and air movement are particularly important. High air velocities and low humidity should be avoided. Air extract ducts should be positioned at low level so that contamination and humidity levels can be effectively controlled. The ventilation rate within a pool hall should be varied based on air quality and humidity. Designing the ventilation system to eliminate the risk of condensation is essential to reduce the need for repairs to roofs, ceilings and windows, and extend the life of decorated surfaces.

- The ventilation system should provide a minimum of 12 litres per second of fresh air for each occupant.
- A guideline figure of 10 litres of ventilation air per second per square metre of pool hall satisfies the requirements of ordinary pools.
- The supply ventilation should be designed to provide 100% fresh air when required.
- A slightly negative pressure in both the pool hall and the changing rooms will help to stop moisture permeating the building structure.
- Pool hall ventilation systems should be provided with low temperature and high humidity control which overrides the time clock control. These systems usually have two speed fans. It may be advisable if out of school hours, the plant starts up occasionally on low speed.
- Pool hall air temperature should be 1^{o}C above pool water temperature.
- Air temperatures should not generally exceed 30^{o}C and relative humidity should be about 50-70%.
- The maximum recommended pool water temperatures are as follows:
  - 27^{o}C competitive swimming and diving, training and fitness swimming.
  - 28^{o}C recreational use, conventional main pools and adult teaching
  - 29^{o}C children's teaching, leisure pools
  - 30^{o}C babies, young children, disabled.

Humidity in swimming pools is difficult to control as it can fluctuate quickly and controllers have poor accuracy. The combination of lowest temperature with highest humidity is usually determined by the winter inside temperature of the glazing. For this reason, double-glazing should be installed as a minimum and more highly insulated glazing should be considered. Where acoustic material is applied to the roof soffit, more thermal insulation will be needed above the vapour barrier to keep the temperature in the acoustic absorbent layer above the dewpoint of the room air, i.e. to avoid interstitial condensation.

Recirculation of exhaust air should be limited to no more than 70% of the supply air volume. This is due to the build up of the products of disinfection (chloramines) which are sometimes a suspected cause of respiratory irritation. Full fresh air systems which dehumidify using outside air and a heat exchanger are usually employed. They provide a healthier, less corrosive atmosphere which can also reduce maintenance of plant, finishes and fittings. Changing rooms should be supplied with 100% fresh air at a high air change rate and are usually kept at a temperature of around 20-25^{o}C. A ventilation system with an insufficient air change rate or fresh air supply will cause uncomfortable and stuffy conditions in the pool hall.

Systems operating with a primary disinfectant such as ozone may release lower levels of chloramine into the pool-side atmosphere and heat recovery and/or heat pump dehumidification allowing recirculation of air can be used.

Ventilation will require both supply and extract with heat reclaim and dehumidification. Heat reclaim from the exhaust air using heat pumps, heat pipes and/or cross-flow heat exchangers to save energy can halve the energy running costs of a typical pool. They usually provide a quick payback and are recommended for both new and existing pools. Dehumidification is needed to prevent condensation on the building structure. When heat pumps are used for dehumidification or heat reclaim they need to be part of the overall ventilation design and their future maintenance needs to be programmed and included in running cost calculations.

Pool covers are the most cost-effective energy saving equipment as they reduce the amount of overnight heating and ventilation needed to protect the fabric from condensation. The client and management must be confident that staff will operate the cover responsibly. The following issues should be noted:

- fully automatic systems are preferred
- irregular pool shapes can be covered
- outdoor heated pools must be covered
- designers should preferably provide the means by which covers can be stored out of the way of the users.

When the pool cover is in position the evaporation of the chemical products of the water treatment process is inhibited. This exacerbates the problems caused by keeping in solution the chlorinated compounds (e.g. chloramines) resulting from water treatment that usually evaporate from the pool surface. After removing the cover, time should be allowed for these concentrations to reduce to acceptable levels before pool use.

Further reading:
Small Public Indoor Pools, Sports Council 1994.
Sports Halls and Swimming Pools: A Design and Briefing Guide, Perrin GA, Spon 1980
Sports Council Handbook Volume 1; SCGN387, Swimming pools - building services.

2.7 Special educational needs and special schools

The requirements for ventilation for mainstream schools are based on a typical occupant density of 30 pupils and one or two staff per teaching space. The occupant density for special schools is much lower and therefore a design rate per person is not appropriate, although the general guidance and advice on ventilation should be adopted. The minimum requirements for ventilation for hygiene and air quality should be as stated in Building Bulletin 77: Accommodation for special educational needs and in special schools. These are summarised in Table 1 below:

Table 1 Provisions for special educational needs and special schools

Space	**Capability for a minimum air change / hour**	**Mechanical / Natural**
Teaching spaces	2.5 ach	Natural if possible, needs to be capable of controlling internal temperature.
Specialist teaching spaces	Supply air should be sufficient to replace process extracted air, control internal temperature and control odour/CO_2 Extract air should be sufficient to meet requirements for fume, steam and dust removal and to control internal temperature and CO_2	Mechanical supply (unless a suitable natural route for make up air can be provided) and mechanical extract will be required to the following areas • Design and technology where required to remove dust and fumes • Science rooms via fume cupboards in addition to other methods. • Sensory rooms • Food technology

		Heat recovery is recommended
Hygiene, lavatory and changing areas, medical inspection rooms and sick rooms	10 ach	Mechanically extracted to outside, provision should be made for make up air, which should be heated and filtered. Heat recovery is recommended.
Laundries, soiled holding or waste, cleaners rooms	5 ach	Mechanical extract with provision for natural or mechanical make up as appropriate
Halls, Gym, Dining, Physiotherapy	Dependent on density of occupation, but based on 8 litres per second per person or 2.5 air changes per hour whichever is the greater	Ventilation should be sufficient to limit CO_2 and control odours.

Guidance for accommodating pupils with special educational needs and disabilities in mainstream schools is specified in BB94: ventilation systems should be controllable and adjustable, according to the needs of individual pupils. Air conditioning should be avoided but where present should be regularly maintained to minimise noise emissions.

BB94 Inclusive School Design Accommodating pupils with special educational needs and disabilities in mainstream schools.

2.7.1 Cross Infection

Children in special schools may be vulnerable to infection. Key infection control policies should be in place and implemented in the planning of a special school. Managing cross infection is a complex subject, but measures can be taken to reduce risk. Adequate source control should help minimise the risk of cross-contamination. The key areas that should be considered are highlighted below:

- Hygiene, wc, shower areas, cleaners rooms, areas holding soiled clothes or clinical waste and laundries should be mechanically ventilated and slightly negatively pressurized relative to adjacent spaces. This also assists odour control.

- Recirculation of air, within areas occupied by pupils, by ventilation, air conditioning or heating system should be avoided as this will increase the risk of cross infection and circulation of allergens. Similarly extract outlets should be positioned to avoid risk of recirculation into a supply inlet or natural ventilation opening. Extract systems or transfer arrangements should be designed to ensure there is no possibility of back draughts from one area to another.

- Supply inlets should draw air from a clean environment and access to ductwork for periodic cleaning should be provided. All exposed services should be designed to avoid collection of dust and contaminants and all services should be easy to access and clean.

Further guidance can be found in Building Bulletin 77**:** Designing for Special Educational Needs, Special Schools.

2.8 Ventilation of other buildings and spaces

The F1 requirement may be satisfied by following the appropriate design guidance for the types of spaces/buildings given in Table 2[10] below. Whilst the table is not specifically aimed at school buildings it is included for completeness.

Table 2 Ventilation of other buildings and spaces – adapted from table 2.3 of ADF

Activity	**Regulations and Guidance**
Animal husbandry	The Welfare of Farm Animals (England) Regulations SI 2000 No. 1870 London: The Stationary Office 2000. The Welfare of Farm Animals (England) (Amendment) Regulations SI 2002 No.1646. The Welfare of Farm Animals (England) (Amendment) Regulations SI 2003 No. 299. BS5502 Buildings and Structures for Agriculture. See also CIBSE Guide B2: 2001, Section 3.24.1
Atria	CIBSE Guide B2:2001, Section 3.4
Broadcasting Studios	CIBSE Guide B2:2001, Section 3.5
Common spaces	These provisions apply to common spaces where large numbers of people are expected to gather, such as shopping malls and foyers. It does not apply to common spaces used solely or principally for circulation. The guidance will be satisfied if there is provision to spaces where large numbers of people are expected to gather for either: **a.** Natural ventilation by appropriately located ventilation opening(s) with a total opening area of at least 1/50th of the floor area of the common space; or **b.** Mechanical ventilation installed to provide a supply of fresh air of 1 l/s per m^2 of floor area.
Communal residential buildings	Designing energy efficient multi-residential buildings, EEBPP Good Practice Guide GPG 192, http://www.actionenergy.co.uk. See also CIBSE Guide B2:2001, Section 3.8
Darkrooms (photographic)	CIBSE Guide B2:2001, Section 3.24.4
High-rise (non-domestic buildings)	CIBSE Guide B2:2001, Section 3.12
Horticulture	CIBSE Guide B2:2001, Section 2.42.6
Healthcare buildings	HTM 2025, Activity database. HBN (various). CIBSE B2:2001, Section 3.13
Museums, libraries and art galleries	BS 5454:2000. CIBSE B2:2001, Section 3.17
Plant rooms	CIBSE Guide B2: Section 3.18
Washrooms/ sanitary accommodation	Same as for Offices in Table 2.1a
Transportation buildings and facilities	CIBSE Guide B2:2001, Section 3.23

[10] Adapted from Table 2.3 of AD F

2.9 Historic School Buildings

Designers involved in work on historic school buildings should recognise the need to conserve the building's special characteristics[11]. Work should aim to improve ventilation to the extent that is needed, and avoid prejudicing the character of the historic building or increasing the risk of long-term deterioration to the building fabric or fittings. Pressure testing can be used to establish if the fabric of the historic building is leakier than a modern building. Advice from the local planning authority's conservation officer will help when deciding on the most appropriate balance between historic building conservation and ventilation.

Designers undertaking sensitive work on historic buildings would benefit from advice on the following issues:

- Restoring the historic character of a building that has been subject to previous inappropriate alteration, e.g. replacement windows, doors and roof-lights.
- Rebuilding a former historic building (e.g. following a fire or filling in a gap site in a terrace).
- Making provisions to enable the fabric to "breathe" to control moisture and potential long term decay problems: see SPAB Information Sheet No. 4, The need for old buildings to breathe, 1986.

Advice on the factors determining the character of historic buildings is set out in Planning Policy Guidance 15: Planning and the historic environment (PPG15)[12].

2.10 Kitchens

Detailed advice on gas installations can be found in the publication Gas Installations for Educational Establishments UP11, Institute of Gas Engineers & Managers, 2004.

Where flueless gas appliances such as cookers are installed, adequate ventilation is required to safeguard against the possibility of incomplete combustion producing carbon monoxide. This may need to be provided by a mechanical system.

The provision of carbon monoxide or oxygen detectors should be considered to warn occupants of dangerous incomplete combustion which can occur if the ventilation is insufficient for combustion or if the cookers are badly maintained. Guidance is available in BS6173:2001 on air supplies required to support combustion where cookers are installed.

Adequate combustion air as required by BS6173:2001 means that ventilation controls may need to be interlocked with gas supplies, e.g. on kitchen extract systems, unless an alternative means of reducing risk to a practicable level can be demonstrated by other suitable methods of working. Also in some situations fire alarm systems must be linked to extract fans to shut down in the event of a fire. Specialist advice on these matters will be required from a suitably qualified engineer.

Where gas cooking appliances are used, the ventilation may be regarded as a "power operated flue" as described in the Gas Safety Regulations[13], and may need to be interlocked with the gas supply as required by BS 6173[14]. This type of ventilation may need to be provided at source in the way of Local Exhaust Ventilation in accordance with COSHH requirements. The HSE guidance

11 British Standard BS 7913:1998 The Principles of the Conservation of Historic Buildings

12 PPG15 www.odpm.gov.uk/stellent/groups/odpm_planning/documents/page/odpm_plan_606900.hcsp

13 Gas Safety Regulations – where to find

14 BS 6173: 2001 *Specification for installation of gas-fired catering appliances for use in all types of catering establishments (2nd and 3rd family gases)*.

note on ventilation of kitchens in catering establishments gives good advice, some of which is applicable to food technology rooms as well as school kitchens[15].

Due to the high ventilation rates required in such spaces pre-heating of the ventilation air should be considered. Heat recovery can be cost effective when a balanced mechanical ventilation system is used.

15 HSE guidance *note – which one ?*

3 Indoor Air Quality and Ventilation

A large proportion of the general populace spend typically 90% of their time indoors. There is therefore growing concern over human exposure to pollutants found indoors, and their potentially adverse effects on the health, productivity, comfort and well-being of occupants. In busy urban areas, the overall exposure levels inside a building are likely to be due to contributions from both internally and externally generated pollutants. To achieve good indoor air quality in schools, it is therefore important to both minimise the impact of indoor sources and to minimise pollutant ingress into buildings by effective design of the building and operation of the ventilation system.

3.1 Indoor Air Pollutants and their Sources

Pollutants emitted indoors originate from occupants and their activities, and also from building and cleaning materials and furnishings. The major indoor pollutants and their sources include:

Carbon dioxide (CO_2) – CO2 is a product of human respiration and is also a product of combustion so may be found in high concentrations in, for example, food preparation areas and in science labs when Bunsen Burners are in use. Exhaled air is usually the principal source of CO2 in schools. CO2 levels inside classrooms are affected by a number of factors including: the number of occupants in the room; their activity levels; the amount of time they spend in the room; and the ventilation rate. A monitoring study in one school showed that typically, CO2 levels in classrooms rose from the start of each day, reached a peak before lunch time at about 12.30, and then decreased over the lunch period when the classroom was empty. After lunch when the classroom was again occupied, CO2 levels again increased, reaching a peak at the end of the school day at 15.30[16].

Odour – Odour is an indicator of poor air quality. It is emitted from people and from various materials that may be found in school buildings. In general teaching classrooms, the internal air quality in schools is determined largely by odour and CO2 levels rather than other pollutants. Historically the level of fresh air provided to a classroom was specified to avoid significant odour as perceived by persons entering the room. Occupants already in the room will not be aware of odour as the olfactory sense rapidly adjusts to an odour[17]. Odours can therefore build up to unpleasant levels and a sufficient fresh air supply is needed to dilute and remove them.

Volatile organic compounds (VOCs) – VOCs are emitted from a wide range of products including: building materials and furnishings (for example, surface finishings and paints); cleaning products; and also from markers, glues and paints used in art classes. Common VOCs in schools include formaldehyde, decane, butoxyethanol, isopentane, limonene, styrene, xylenes, percholoethylene, methylene chloride, toluene and vinyl chloride[18].

Some VOCs are known to be toxic and can adversely affect children in vulnerable groups (for example, those that suffer asthma and allergies). There are also suggested links between VOC levels and behavioural problems in children. At the levels found in school buildings however, their most likely health effect is short term irritation of the eyes, nose, skin and respiratory tract. Odour generated by VOCs is usually of more concern to the occupants. Formaldehyde is a particularly strong smelling VOC. Although formaldehyde is carcinogenic the concentrations in buildings do not represent a significant risk. Approved Document F[19] suggests concentrations of 0.1 mg/m^3 may cause throat and nose irritation.

[16] Kukadia V., Ajiboye P. and White M. (2005). Ventilation and Indoor Air Quality (IAQ) in Schools. BRE Information Paper, 2005.
[17] Fanger P. O. (1988). Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy and Buildings, No. 12, 1988.
[18] www.aerias.org/uploads/Linking%20IAQ%20and%20Asthma%20in%20Schools.pdf
[19] DoE (1994), Department of the Environment and the Welsh Office, The Building Regulations 1991, Approved Document F1: Means of ventilation (1995 edition). London, HMSO. *Under revision*.

Moisture/humidity – Moisture is generated through occupant activities, for example cooking. High humidity in spaces such as kitchens, bathrooms, gym areas and changing rooms can lead to moisture condensing on cold surfaces resulting in fabric decay and mould growth. Airborne fungi and dust mites can also be a problem. Dust mites in particular prefer moist warm conditions for survival and their droppings are known to cause allergic reactions in some people.

Ozone – Ozone is emitted from office equipment such as photocopiers and laser printers and has been known to cause respiratory problems. This type of office equipment is usually fitted with carbon filters to minimise emissions. However, without an effective maintenance regime, ozone concentrations can rise to unacceptably high levels.

Carbon monoxide (CO) – CO is a product of incomplete combustion and is generated from, for example, gas cookers, gas water heaters and smoking. It is odourless, colourless and tasteless and is potentially fatal at high concentrations.

Particulate matter – Typical indoor particles include smoke particles, spores, biological fragments and fibres. Some of these particles are known to be hazardous to health, for example, fibres from MDF, asbestos and bacteria. Normal control measures which apply in schools, such as the COSHH procedures and Asbestos Regulations, should limit the risks to an acceptable level. The health implications of smaller airborne particles (for example Polycyclic Aromatic Hydrocarbons from motor vehicles and particles from diesel exhaust fumes) are not yet fully resolved but they are unlikely to present a problem in school buildings unless there are high levels of external pollution.

Environmental tobacco smoke (ETS) – Smoking affects both those who smoke actively and those exposed to the products of other people's tobacco smoking and the air exhaled from their lungs (passive smoking). ETS is a known carcinogenic and poses a serious health risk to children, particularly those suffering from asthma.

3.1.1 Minimising Indoor Pollutants

There are a number of methods available for indoor air pollutant control. These include:

Emission control

Potentially harmful emissions from avoidable sources can be reduced by, for example, careful selection of materials to minimise VOC emissions. This may allow ventilation rates to be lowered, thus providing a potential saving in energy use. Emission control is not considered within the main guidance of Approved Document F due to limited knowledge about the emission of pollutants from construction and consumer products used in buildings, and the lack of suitable labelling schemes for England and Wales[*]. Some construction products such as glass, stone and ceramics have low emissions. Some paints are now labelled for their VOC content, and some wood-based boards are available with low formaldehyde emission[20]. Labelling allows suitable products to be chosen in ensuring good indoor air quality, but it is not currently practical to make an allowance for use of these products in the ventilation requirements. However, work is continuing in this area for inclusion in future revisions of Approved Document F. Further information about control of emissions from construction products is available in BRE Digest 464[21], and information on source control to minimise dust mite allergens is available in BRE Report BR 417[22].

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[*] In Denmark, for example, the Danish Indoor Climate Labelling Scheme (DICL) assesses the impact of building materials and products on the indoor environment. The scheme covers testing, emissions and decay rates for 10 product areas including interior paints, furniture and carpets. More information can be found at http://www.danishtechnology.dk/building/13268

[20] BS EN 13986: 2002 Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking.

[21] BRE Digest 464: VOC Emissions from Building Products Parts 1 and 2; IP 12/03 VOC Emissions from Flooring Adhesives.

[22] Raw G. J., Aizlewood C. E. and Hamilton R. M. (2001). Building Regulation, Health and Safety. BRE Report 417, 2001.

Discouraging tobacco smoking

Discouraging tobacco smoking is another means of emission control by which harmful emissions of CO and smoke particles can be reduced. It is recommended that smoking is not allowed in school buildings (Report of the Scientific Committee on Tobacco and Health, 1998)[23]. However, if the school management choose to provide a room specifically for the use of smoking members of staff, non-smoking staff members and children outside the room must be protected from passive smoking. The ventilation requirement for the smoking room can be met by an air extract rate of 36 l/s per person directly to the outside, and an appropriate supply of make-up air which is designed to maintain a slightly lower pressure (at least 5 Pa) inside the smoking room than in adjoining parts of the building. It is essential that the ventilation system is operated correctly and is well maintained. In addition, the smoking room should be located such that children never need to enter it, and any door to the smoking room should have an automatic closer. These provisions will not protect the health of those using the room, and may not be sufficient to protect the health of those outside the room, but should be sufficient to control odours. If the designated smoking areas are outside, these should be located away from doors, windows and ventilation inlets.

It is recommended that designers consult current guidance on passive smoking at work issued by the Health and Safety Executive (HSE). This guidance is designed to help employers meet their responsibilities under Section 2(1) of the Health and Safety at Work Act 1974 to protect the health, safety and welfare of their employees. HSE booklet Passive Smoking at Work (IND(G)63(L)Revised) offers advice to employers on ways to reduce the exposure of their employees to tobacco smoke. The best approach to adopt depends on what is reasonably practicable in a particular workplace, in this case, a school. Local Authority Circular 91/1 also gives advice to local authority enforcement officers on how to enforce the requirements of the 1974 Act in the context of passive smoking in the workplace. Both of these documents are available free of charge from the HSE website (www.hse.gov.uk).

3.2 Outdoor Air Pollutants and Sources

A wide range of pollutants are generated outdoors and are either known or suspected of adversely affecting human health and the environment. Key urban pollutants that need to be considered include those covered by the UK National Air Quality Strategy (NAQS) (DETR, 2000)[24]. These are:

- Carbon monoxide, CO;
- Nitrogen dioxide, NO_2;
- Sulphur dioxide, SO_2;
- Ozone, O_3;
- Particulate matter, PM_{10};
- Benzene;
- 1,3-Butadiene;
- Lead.

Although Nitrogen oxide, NO, is not included in the NAQS, it is a normal constituent of combustion discharges, and in many cases (for example, from gas fired plant) the largest polluting emitter. Therefore NO also needs to be taken account of. However, NO is chemically reactive and readily oxidised to NO_2.

Sources of outdoor pollutants include:

- Road transport. This includes traffic junctions and car parks (underground car parks in particular), and traffic generating developments. In urban areas, emissions and noise from road transport sources can adversely affect the indoor environment;
- Combined heat and power plant (CHP);

[23] http://www.archive.official-documents.co.uk/document/doh/tobacco/contents.htm

[24] Department of the Environment, Transport and the Regions, The Scottish Executive, the National Assembly for Wales and the Department of the Environment for Northern Ireland. The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. The Stationery Office, United Kingdom. ISBN 0 101454 82 1.

- Other combustion processes (for example, waste incinerators and boilers);
- Discharges from industrial processes. Industrial emissions include a wide range of substances such as lead, VOCs, smoke, ozone and oxides of nitrogen and sulphur;
- Fugitive (i.e. adventitious/not effectively controlled) discharges from industrial processes and other sources;
- Building ventilation system exhaust discharges;
- Construction and demolition sites. These are sources of particles and vapourous discharges;
- Agricultural processes. In intensively farmed areas, pollen and fungi can be a problem, as can fertilisers and insecticides;
- Soil borne pollutants. These include methane and radon. They can enter the building via cracks or penetrations in the foundations or other parts of the building envelope.

3.2.1 Ingress of Polluted Outdoor Air into Buildings

In urban areas, buildings are exposed simultaneously to a large number of individual pollution sources from varying upwind distances and heights, and also over different time scales. The relationship between these and their proportionate contribution under different circumstances governs pollutant concentrations over the building shell and the degree of internal contamination.
Internal contamination of buildings from outdoor pollution sources therefore depends upon:

- The pollutant dispersion processes around the buildings;
- The concentrations of pollutants at the air inlets;
- The ventilation strategy (natural, mixed-mode, mechanical);
- Pollution depletion mechanisms;
- The airtightness of the building (i.e. the ability of the building envelope to prevent the uncontrolled ingress of pollutants).

Further information can be found in Kukadia and Hall (2004)[25].

3.2.2 Minimising Ingress of Polluted Outdoor Air

3.2.3 Ventilation air intake location

It is important to ensure that the intake air is not contaminated regardless of the type of ventilation system in operation. This is especially important in Air Quality Management Areas[26] where by definition pollution levels of at least one pollutant have exceeded the Air Quality Standards[27]. The siting of exhausts and fume cupboard discharge stacks is also important – this is discussed in Section 4.3.4.

Guidance on ventilation intake placement for minimising ingress of pollutants is summarised in Table 3 (reproduced from Approved Document F). The guidance given in Table 3 is greatly simplified and cannot be applied to all sites. The risks associated with specific sites may need to be assessed either through guidance from an expert or by physical modelling.

3.2.4 Control of ventilation intakes

For pollutant sources such as urban road traffic, whose concentration fluctuates with the time of day, reducing the flow of external air or closing ventilation intakes during peak periods of high external pollutant concentrations, for example during rush hours, for up to an hour may be an option. This would need automated control operated on at least a timed basis and more probably

[25] Kukadia V. and Hall D. J. (2004). Improving Air Quality in Urban Environments: Guidance for the Construction Industry. BR 474, ISBN 1 86081 729 7, Buiding Research Establishment.

[26] See www.airquality.co.uk/archive/laqm/laqm.php

[27] Air Quality Management (2002). Air Quality Strategy Wallchart – Summary of Proposed Objectives in the Latest Consultation, November 2002. GEE Publishing.

with a sensor for the relevant pollutant. Closing the air inlets may also be desirable to prevent noise ingress.

Air intakes located on a less polluted side of the building may then be used for fresh air, or air may be fully re-circulated within the building. Alternatively, the building may be used as a 'fresh air' reservoir to supply air during these short periods. The use of atria as a source of 'fresh air' for this purpose may be an option but noise transfer through the atria can make this difficult – see section 4.3.2. Schools tend to have an advantage over other buildings as, classrooms tend to have fairly high ceilings. In modern schools corridors tend to be used as resource areas so have large volumes and there is usually an assembly hall and/or a gym.

However, care must be taken since for example, reducing the inflow of external air will also reduce the outflow of internal air resulting in a build up of internally generated pollutants that need to be removed. Some modern buildings have low ceiling heights and therefore the concept of a substantial 'fresh air ' reservoir available within the building may not apply. For this reason a minimum floor to ceiling height of at least 3m is desirable in a naturally ventilated classroom or other teaching space. This is even more desirable in science labs, prep rooms and worhshops where activities may result in higher pollutant emission. Further details of this principle with examples may be found in Liddament M.W. (2000) Chapter 13: Ventilation strategies. Indoor Air Quality Handbook. McGraw-Hill.

3.2.5 Location of exhaust outlets

The location of exhausts is as important as the location of air intakes. Exhausts should be located to minimise re-entry to the building, for natural and mechanical intakes, and to avoid adverse effects to the surrounding area. Guidance on outlet placement is summarised as follows.

- Exhausts should be located downstream of intakes where there is a prevailing wind direction.
- Exhausts should not discharge into courtyards, enclosures or architectural screens as pollutants do not disperse very readily in such spaces.
- It is recommended that stacks should discharge vertically upwards and at high level to clear surrounding buildings and so that downwash does not occur.

Where possible, pollutants from stacks should be grouped together and discharged vertically upwards. The increased volume will provide greater momentum and increased plume height. This is common practice where there are a number of fume cupboard discharges; greater plume height dispersion can be achieved by adding the general ventilation exhaust.

Table 3 Guidance on ventilation intake placement for minimising ingress of pollutants (reproduced from Approved Document F).

Pollutant Source	Recommendation
Local static sources: • Parking areas; • Welding areas; • Loading bays; • Adjacent building exhausts; • Stack discharges.	Ventilation intakes need to be placed away from the direct impact of short-range pollution sources especially if the sources are within a few metres of the building. Some guidance is given in CIBSE TM21[28].
Urban Traffic	Air intakes for buildings positioned directly adjacent to urban roads should be as high and/or as far away as possible from the direct influence of the source so as to minimise the ingress of traffic pollutants. There will be exceptions to this simple guide and these risks may need to be assessed by modelling. In such cases it is recommended that expert advice is sought. For buildings located one or two streets away, the placement of intakes is less critical.
Building Features/Layout: Courtyards: Street Canyons:	 Intakes should not be located in these spaces where there are air pollutant discharges. This includes emission discharges from building ventilation system exhausts. If air intakes are to be located in these spaces, they should be positioned as far as possible from the source in an open or well-ventilated area. Steps should also be taken to reduce the polluted source e.g. parking and loading should be avoided as pollutants can accumulate in enclosed regions such as courtyards.
Multiple Sources	Where there are a large number of local sources, the combined effect of these around the façade of the building should be assessed. The façade experiencing the lowest concentration of the pollutants would be an obvious choice for locating ventilation intakes but this will require expert assistance such as numerical and wind tunnel modelling. In general, however, it is recommended that the air intakes be positioned as far as possible from the source at a location where air is free to move around the intake.
Weather Factors	In areas where predominant wind comes from opposing directions (e.g. a valley location) the air intakes and outlets should point in opposite directions. In complex urban layouts, complex wind flows are likely to occur. In these cases, expert advice may be required.

[28] CIBSE (1999). CIBSE Technical Memorandum TM21 on Minimising Pollution at Air Intakes. Chartered Institute of Building Services Engineers, 1999. ISBN 0 900953 91 8.

Filtration

Filtration provides a means of cleaning the intake air and filters are fitted as standard to mechanical ventilation systems. Mechanical systems can, on account of this, be perceived as providing cleaner air to the space. However, is must be noted that filtration systems are selective and are only effective at dealing with the pollutants they are designed for. Mechanical ventilation system air intake filters are primarily used for particle removal. If it is necessary to remove gaseous pollutants, then activated carbon filters are required. This is an exceptionally demanding and costly process. Therefore, it is preferable to ensure the ingestion of better quality of outside air by effective ventilation inlet placement, where this is possible.

Building airtightness

To prevent the uncontrolled ingress of contaminated outdoor air, it is important that the building envelope should be airtight. Currently building airtightness is seen only as an energy issue and airtightness requirements are covered in Part L of the Building Regulations (2002). This specifies minimum performance requirements in terms of air permeability. Air permeability is defined as the air leakage in m^3h^{-1} per metre square ($m^3h^{-1}m^{-2}$) of building envelope area, which includes the ground-supported floor area, at a reference pressure of 50 Pa. The maximum permitted value specified by Part L is 10 $m^3h^1m^{-2}$. All buildings over 1000 m^2 gross floor area have to be tested to meet this criteria. Full details on achieving and verifying performance are given in CIBSE TM23[29]. Discussions on introducing even tighter requirements are on going. Construction and retrofit, to at least the current Regulations, should be regarded as essential to prevent the uncontrolled ingress of pollutants.

[29] CIBSE (2000). CIBSE Technical Memorandum TM23 on Testing Buildings.

4 Ventilation strategies

4.1 Ventilation System

Traditionally schools have been designed for natural ventilation and good daylighting. This resulted in narrow plan schools provided with large areas of openable windows, often offering cross ventilation combined with stack ventilation by clerestory windows. Studies have shown that this can provide the required level of fresh air but that typically classroom occupants are not able to exploit the full potential of the ventilation and accept a slightly reduced level of air quality because of problems of operation or draughts.

The current trend in school design is towards deeper plan spaces to make more efficient use of the available land area, together with the increase in ICT in schools this has led to concerns about overheating in the classrooms. This has stimulated increased interest in ventilation systems – both natural and mechanical - that will perform better than the simple window opening approach of previous designs.

4.1.1 Natural Ventilation

Purpose designed natural ventilation, as opposed to simple window opening strategies, can provide the following advantages:

- Lower running costs through lower energy consumption
- Decreased capital costs
- Decreased maintenance costs
- Reduced energy use by fans to transport the air
- Fewer problems from plant noise
- Sound insulation of the building envelope reducing the ingress of traffic noise.

Naturally ventilated buildings are cheaper to construct than equivalent mechanically ventilated buildings, as a rule of thumb they cost 10-15% less to construct. A significant reduction in the cost of the engineering services usually more than compensates for some extra costs in envelope improvements, such as external shading and openable windows or sound attenuated ventilation openings. Smaller plant may also require less plant room space.

Naturally ventilated buildings have no HVAC systems and as a consequence can achieve low energy consumption. Fan energy is avoided as air movement is achieved through well-designed opening windows other ventilation openings or more sophisticated ventilation stacks and flues, which make use of wind and buoyancy effects. This results in significantly lower operating and maintenance costs.

However, for all of these benefits to be realised care must be taken to design the natural ventilation system correctly. This will entail giving consideration to the size and location of openings; ClassVent (available from the DfES website) is a simple tool that will greatly assist in the design process. To increase the occupant satisfaction the ventilation system must be controllable and integrated in such a way that draughts are voided.

4.1.2 Hybrid Ventilation

A potentially more environmentally and financially sound solution is to adopt a ‘hybrid’ or mixed mode ventilation strategy. The underlying principle of a hybrid system is that the school is designed as a naturally ventilated building – without ductwork for air transport – but provision is made to assist the air flow through the space when natural driving forces are inadequate. The use of hybrid ventilation therefore can have reduced capital costs of ventilation ductwork and reduced cleaning costs.

Hybrid ventilation is often preferred to a full mechanical system as it is highly suited to a design using night cooling of the building fabric. Using the thermal mass of the building fabric allows the designer to avoid comfort cooling and the costs and space that are required for plant rooms and associated ductwork. To ensure that the air flow is not restricted care must be taken with partitioning and the use of down-stand beams that may interrupt the air flow and its contact with exposed soffits.

A concern that future uses of the school or trends in climate may require the adoption mechanical ventilation is also addressed in CIBSE AM13, which provides a very detailed description of mixed-mode and hybrid ventilation, and should be consulted before a full mechanical ventilation system is installed.

4.1.3 Mechanical

Mechanical systems are expensive but a significant advantage is the option to provide heat recovery. Heat recovery with a mechanical ventilation system is energy efficient but this heat recovery is not sufficient to make a mechanical system fully cost effective – even when used together with heat recovery. Currently no suitable technology for heat recovery exists in natural ventilation designs. This may lead to mechanical ventilation being economically attractive in special cases such as ICT rooms. However, mechanical ventilation alone will not remove large quantities of internal heat gains in the summer, when they are most problematic, because of the limited extent to which the air can transport the excess heat.

Comfort cooling, with all the associated costs, then becomes necessary. If mechanical ventilation is being considered a whole life cost calculation should be carried out as part of the option appraisal including initial capital and installation costs; maintenance and replacement costs; operational electricity costs and, where heat recovery is included, the cost of gas for space heating or DHW.

4.1.4 Local ventilation

Local extraction is required from processes or rooms where water vapour and/or pollutants are released through activities such as showering, cooking or chemical experiments. This is to minimise their spread to the rest of the building. The exhaust ventilation may be either intermittent or continuous – (see Table 1 ADF p54). Provision should be made to protect the fresh air supplies from contaminants hazardous to health.

Local extract to outside is required in all sanitary accommodation, washrooms and food and beverage preparation areas. In addition, printers and photocopiers used frequently or continuously, should be isolated (to avoid any pollutants entering the occupied space) and local extract provision installed. This also includes fume cupboards and local exhaust hood type vent systems that remove pollutants at source. The recommended minimum extract flow rates are given in Table 4. Photocopiers have active carbon filters which if well maintained will limit ozone emissions. Information about the maintenance of photocopiers can be found in Local Authority Circular: LAC 90/2.

Table 4: Ventilation rates for local extract

Room	Local Extract
Rooms containing printers and photocopiers in substantial use (greater than 30 minutes per hour)	Air extract rate of 20 l/s per machine during use. Note that if operators are continuously in the room, use greater extract and whole building ventilation rates

Sanitary accommodation and washrooms.	Intermittent air extract rate of: • The lesser of 6 ach (SPR 4) or: • 15l/s per shower/bath • 6l/s per WC
Food and beverage preparation areas (not commercial kitchens); including food technology areas.	Intermittent air extract rate of: • 15 l/s with microwave and beverages only • 30 l/s adjacent to the hob with cooker(s) • 60l/s elsewhere with cooker(s) All to operate while food and beverages preparation is in progress.
Specialist rooms (e.g. commercial kitchens, fitness rooms)	See Table 2.3

4.2 Ventilation and heating

The energy required to condition the outdoor air in winter can be a significant portion of the total space-conditioning load, and increasingly so as fabric insulation increases. Air exchange typically represents 20 to 50% of a building's thermal load and this is one reason to limit air exchange rates in schools to the minimum required. An energy efficient design aims to provide thermal comfort and acceptable indoor air quality with the minimum use of energy. In winter, any fresh air above that required for controlling indoor air quality represents an energy penalty. This means that careful thought needs to be given to the detailed design of the ventilation system.

Natural ventilation can contribute to a sustainable environment by reducing the electrical energy used in buildings. Most naturally ventilated buildings are narrow plan, and this can allow increased utilisation of daylight, thereby reducing demand for electric lighting in addition to the reduced energy demands of ventilation fans and air handling plant. Mechanical ventilation is a primary energy intensive process and air conditioning is even more so.

The interaction between ventilation and the heating system should also be considered. For example, the heating system should be sized to provide heat for the incoming fresh air based on the lower heat load that corresponds to 5l/s/person – not the capability of 8l/s/person.In addition, when the school is occupied the internal heat gains often provide a large part of the ventilation heat loss and most heating is pre-heat when fresh air supply should be minimal.

If an area of the building gets too warm (e.g. by solar gain through a window), the instinctive reaction of the occupant is likely to be to open the window rather than to turn down the heating. The use of localised controls will minimise this potential conflict. More sophisticated techniques include interlocks between the heating system and window opening.

4.3 Acoustics

There is a strong relationship between ventilation and acoustics, particularly with natural ventilation. Natural ventilation systems generate no noise themselves but they do allow external noise, for example from traffic, into the building. A passage provided for the flow of ventilation air – either internally or from the outside – also becomes a path for noise. The standards of acoustic performance now required for schools, as determined by BB93 and the Building Regulations, demand careful consideration of the interaction of the ventilation strategy and the acoustic performance of the building. Experience has shown that some good natural ventilation strategies have not worked in practice because of the transmission of unwanted sound.

4.3.1 External Noise

Noise from road vehicles, rail and air traffic, is often cited as a major constraint on the use of natural ventilation. For an external free field A-weighted noise level[30] dominated by road traffic, facades with open windows attenuate the noise into a classroom with 0.5 second reverberation time by between 8 dB and 14 dB. Therefore the external free field noise should not exceed 49 dBA for the indoor noise level to be below 35 dBA.. Where classrooms are located on the noisy facades opening windows may not be possible but roof-mounted ventilators, or sound-attenuated openings might be an option.

Before adopting a natural ventilation strategy, the required indoor ambient noise levels in the different spaces in the building and external noise levels will need to be established. It is usually advisable to employ a noise specialist to do this and to look at possible options to attenuate the external noise. In some cases constant levels of road traffic noise, for example from distant arterial roads may be desirable to mask noise from other classrooms, however specialist acoustic advice is probably needed. Generally it is possible to develop strategies to avoid or control external sources of noise and still use natural or hybrid ventilation techniques.

An increasing range of components providing air flow and noise attenuation are available to control noise ingress from outside and sound transmission between spaces. Reference to Building Bulletin 93[31] and suitable case studies is essential for a full understanding of the issues.

Section 1.2.1 of BB93 permits the use of Alternative Performance Standards which provides further scope for designers to increase the indoor ambient noise levels on a selective basis where the designers consider that for environmental, educational or health and safety reasons it would be preferable to allow a higher indoor ambient noise level. Cases where this option has been pursued are where the external noise level is particularly uniform, e.g. in the case of a distant motorway or where the higher noise levels occur only at certain times of the day or week.

4.3.2 Internal Noise

Since the introduction of BB93, some design teams have not used cross ventilation between classrooms and corridors, or between classrooms and atria, due to the difficulty in achieving the required sound insulation between these spaces when they are linked by a ventilator. In general, ventilation paths across partitions significantly reduce the airborne sound insulation of that partition unless they use a ventilator that has been acoustically treated. However, the addition of sound absorbent material in a ventilator also reduces its efficiency as a ventilation path, and it can sometimes be difficult to reconcile the demands for sound insulation and ventilation. Acoustically attenuated ventilators can be used to satisfy normal loads and be supplemented by boost fans for periods requiring higher ventilation such as intensive use of IT or summer overheating.

Research[32] into the sound attenuation and airflow characteristics of different configurations of a prototype ventilator intended for cross flow ventilation in schools show that eight of the prototype ventilator configurations that were tested had sufficiently high airborne sound insulation to satisfy the BB93 performance standards. In addition the airflow tests indicate that although the equivalent areas are reduced due to the presence of sound absorptive material inside the ventilator, the values are still sufficiently high to allow cross ventilation. See - *IP 4/99 Ventilators: ventilation and acoustic effectiveness*

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30 Free field describes a sound field in which the effects of obstacles or boundaries on sound propagated in that field are negligible. A-weighted describes a sound containing a wide range of frequencies in a manner representative of the ear's response, with the effects of the low and high frequencies reduced with respect to the medium frequencies.

31 Building Bulletin 93: Acoustic Design of Schools – a design guide. .pdf available at http://www.teachernet.gov.uk/management/resourcesfinanceandbuilding/schoolbuildings/designguidance/sbenvironmentalhs/acoustics/

32 BRE Client Report : A prototype ventilator for cross ventilation in schools: Sound insulation and airflow measurements.Client report number 220497

4.3.3 Mechanical ventilation noise

Mechanical ventilation systems are not silent and the standards in BBB93 are seen as challenging even for full mechanical systems. Fans can generate noise that can travel easily through ductwork to occupied spaces. To overcome this, designers can put noise attenuators either in the ductwork or as part of the ventilation plant or specify quieter equipment. Attenuators in ductwork systems add to the capital costs and increase pressure losses which increases the fan power required. Higher fan power results in greater energy use and therefore higher running costs. Ventilation plant and chillers that are manufactured to low noise levels are more expensive than standard units or will involve special acoustic enclosures that take more space and cost more.

The designer is advised to consider the noise produced by any proposed mechanical system earlier in the design process as it may limit some design solutions. It should also be remembered that mechanical systems should provide 8l/s per person at all times and the indoor ambient noise levels given in BB93 Table 1.1 should not be exceeded when mechanical ventilation system is operating at its maximum specified air flow rates.

The noise from ventilator actuators can be a problem. This noise is intermittent and where automatic systems are not under user control, relatively low noise levels can be very disruptive to class activities. Therefore it is essential that the noise of these actuators is kept well below the indoor ambient noise levels given in Table 1.1 of Building Bulletin 93.

4.4 Fire precautions

Note that Approved Document B includes provisions for the size of escape windows. If the openable area required for fire escape is larger than that required for ventilation it should apply in all cases.

Fire precautions may be required to ensure that compartmentation and escape routes are not prejudiced by the presence of passive stack ventilation ducts. Guidance on such fire precautions may be found in Building Regulations: Approved Document B.

New government guidance on fire safety for schools is also being produced. Building Bulletin 100, "Designing against the risk of fire in Schools", will give guidance on the design of new schools as well as the refurbishment of existing schools.

4.5 Interaction of mechanical extract ventilation and open flued combustion appliances

Extract fans can cause the spillage of combustion products from open-flued appliances by lowering the pressure in a building. This can occur even if the appliance and the fan are in different rooms. Ceiling sweep fans produce air currents and hence local depressurisation which can also cause the spillage of flue gases from open-flued gas appliances or from solid fuel open fires. In buildings where it is intended to install open-flued combustion appliances and extract fans, the combustion appliance should be able to operate safely whether or not the fans are running. In these circumstances, compliance can be demonstrated by following the guidance given in *Approved Document J* on the installation of the appliances and conducting tests to show that combustion appliances operate safely whether or not fans are running.

4.6 Access for maintenance

For all ventilation systems reasonable provision should be made to maintain the components a nd this would include:

a. Access for the purpose of replacing filters
b. Access points for cleaning duct work.

In a central plant room adequate space should be provided, as necessary, for the maintenance of the plant. Where no special provision is required, a space of 600mm could be adequate where access is required between plant and 1000mm where space for routine cleaning is required (see Diagram 5). These figures represent the minimum space needed; additional space may be needed for opening access doors, withdrawal of filters etc.

Further guidance for more complex situations can be found in Further guidance for more complex situations can be found in Defence Works Functional Standard, Design & Maintenance Guide 08: *Space requirements for plant access operation and maintenance.* [33]

5 Designing for Natural Ventilation

5.1 Basic Ventilation Principles

The starting point in ventilation design is to determine how much ventilation air is required and for what purposes. For indoor air quality, as pointed out above, the requirement for school classrooms is based on each person being capable of receiving 8l/s of fresh air. This design capability is needed at all times in winter and summer. Often it is also necessary to design for the cooling effect of external air, as in night time cooling of the thermal mass of the building. Night cooling can require a greater flow of external air.

This section outlines the basic principles underlying natural ventilation and explains how best to proceed with a specific design. It is not intended to be a textbook of natural ventilation, the main aim is to assist school designers to quickly establish how their school building may be naturally ventilated.

DfES has provided a ClassVent calculator to be used with BB 101 that enables a designer to rapidly calculate areas for air flows into and out of a classroom. Designs using the ClassVent calculator could be deemed to satisfy the guidance given in Section 1.5 of this Building Bulletin. Other design tools can also be used but calculations for these designs and would likewise need to be submitted for building control approval.

The ClassVent tool is available from the DfES website and together with it are reports outlining the development of the ventilation requirements for schools and the testing of the ClassVent tool.

5.2 Natural Ventilation Driving Forces

Natural ventilation is mainly driven by two mechanisms:

- Stack effect
- Wind pressure.

The stack effect arises from the decrease in density of air as its temperature increases. Generally, higher temperature internal air will have a lower density than the cooler outside air. If a boundary separates these two masses of air there is a pressure difference across the boundary. At either ends of the boundary, or openings in the boundary, air will flow across the boundary from the high to the low pressure. Normally, this therefore provides a flow of air into the lower part of a building and out of the higher part of the building. The greater the height of the boundary, or stack of air, the greater the overall pressure difference.

The stack effect does not actually need to have a physical ‘stack’ or chimney. Two separate openings in a wall in a classroom that is warmer than outside will experience a pressure difference and air will flow into the lower opening and out of the upper opening. Because the stack effect

33 Ministry of Defence, ISBN 0 11 772785 7. Available from the Stationery Office, 1996

relies on temperature differences as the temperatures inside and outside become more equal (in summer for example) the pressure drop across the openings decreases and the ventilation rate will decrease. To counter this effect openable areas must be increased.

Wind pressure also influences the ventilation of a building by creating variations in pressure over and around the outside of the building. Variations in pressure are highly dependent on the building form and the wind speed and direction. Typically, the façade facing the wind will experience an increase in pressure and the other façades of the building will experience a negative pressure. However roofs can be subject to either positive or negative pressures. These effects are dealt with by the use of appropriate wind pressure coefficients that are included with most ventilation simulation programmes.

Wind pressure coefficients are available for a wide range of building forms but they will only generally apply to quite simple regular shapes and particular wind patterns. For more complex building designs the determination of wind pressure coefficients may require experimentation in a wind tunnel.

The stack effect and wind effect can combine to increase the overall driving forces but can also oppose each other and result in no overall pressure difference, and therefore no ventilation air flow. Even though the wind speed is typically greater than 3m/s for most places in the UK, and will often assist the stack effect it is best to design for a still, or relatively calm, day as this is the most challenging condition. At the early design stages it is advisable to adopt simple strategies that rely on the more predictable stack effect, particularly if detailed information about wind pressure coefficients and wind speed and direction are not available.

The more simple natural ventilation calculations are approximations based on the bulk properties of the air and are open to error but even detailed CFD models used by a highly skilled modeller will not necessarily improve on the accuracy of simple empirical equations. Therefore the simple *Classvent* model available on the DfES website www.teachernet.gov.uk/iaq is probably a good starting point for proving the adequacy of natural ventilation designs as part of submissions to Building Control Bodies.

5.3 The Range of Ventilation Strategies for a Typical School

A number of ventilation strategies, accommodating most situations, are open to the designer. The Classvent programme allows the user to choose one of the following ventilation strategies:

- Single sided ventilation
- Single sided ventilation with high and low level openings
- Cross ventilation and cross ventilation with height difference
- Stack ventilation
- Multiple classrooms with stack ventilation served by a corridor or atrium.

These strategies are illustrated in the figure below.

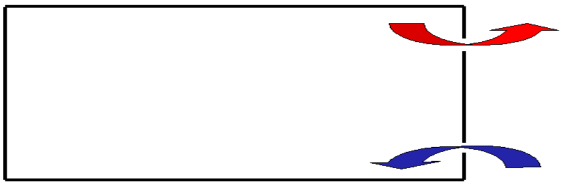
Roof-mounted ventilators[34] are also possible. These use the pressure difference across the segmented ventilation device to drive air down through the segment facing the wind and into the space. The suction created by the negative pressure on the leeward segment draws the air back out of the space. Actuators can be used to control the flow rate and diffuser modules to achieve air distribution. Roof-mounted ventilators are not currently included in the Classvent tool.

[34] For more information see BSRIA guide BG12/2004 Wind-Driven Natural Ventilation Systems

Choose your Ventilation strategy by clicking on the image

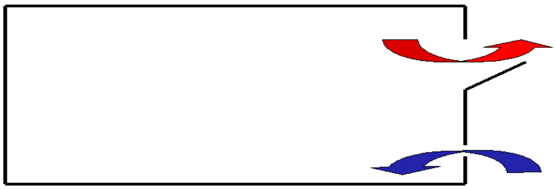
Single Side Ventilation, One Vent or Window.

One Ventilation opening, normally one grille at low level.
Air Flows in from the lower part of the vent and out from the upper part.
User specifies depth of the opening and height from floor to middepth of
The work sheet gives the area of the opening.
Note:- this option could be used to simulate a window, but in this case it n



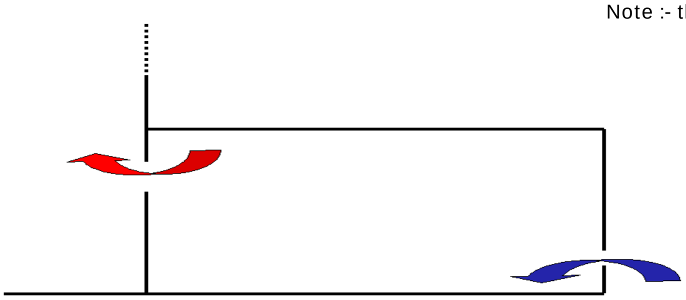
Single Side Ventilation, Twin Identical Vents (same area).

Two ventilation openings, normally one Grille at low level and one at high
Air Flows in from the lower vent and out from the upper vent.
User specifies the height from floor to middepth of the openings.
The work sheet gives the area of the individual openings.



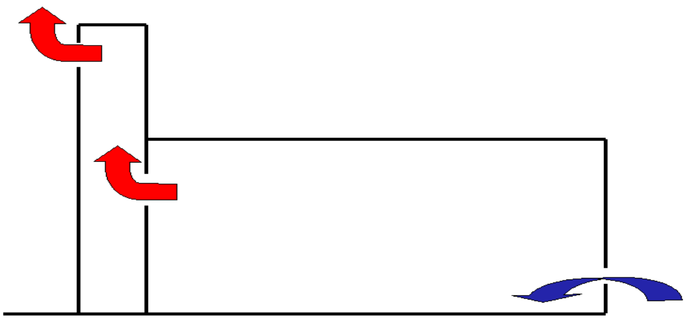
Single Side Ventilation, One Vent and One Openable Window.

Two ventilation openings, a low level grille and one openable window.
Air flows in from the lower vent and out from the window.
User specifies the height from floor to middepth of the vent and the open
of the window, as well as its openable area.
The work sheet gives the area of the vent as function of the openable wir
Note :- this window must be kept open at all time to comply with BB87



Cross Flow Ventilation, One Vent on the front Façade one on the

Two ventilation openings, a low level grille and high level one, t
Air flows in from the front and out in the corridor or any adjacen
User specifies the height from floor to middepth of the openings
The work sheet gives the total area of the openings.
The user can also specify an area for the window.
The work sheet gives the area of the individual openings, or, I f t



Stack Ventilation, One Vent on the front Façade one on the bac

Two ventilation openings, a low level grille and high level one, t
Air flows in from the front and out via the corridor or any adjace
User specifies the height from floor to middepth of the openings
The work sheet gives the total area of the openings.

Figure: Range of ventilation strategies available in the Classvent tool

5.4 *Design Stages*

It is possible to consider natural ventilation design as a three stage process:

- Concept design
- Scheme design
- Detailed design

This section discusses the information needed for each of these stages and the resulting design solutions. The guidance in this document is supplemented by the customised spreadsheet design tool ‘ClassVent’ developed for school classrooms by DfES [35].

5.4.1 Concept Design Stage

It is imperative that the ventilation strategy is considered at the earliest design stages of the school i.e. at the concept design stage. It can be extremely difficult to incorporate natural ventilation in a building when fundamental design choices have already been made. For example, deep plan and lightweight construction can render a successful natural ventilation strategy impossible. It is therefore important to involve the ventilation designer in the earliest design stage. The table below highlights key design features which make natural ventilation successful or more difficult.

Success Factors	Problem issues
Narrow plan	Deep plan
Two sided façade	Single sided narrow plan
High ceilings	Low ceiling heights
Thermally heavy weight construction	Thermally light weight construction
Controlled internal gains	High incidental heat gains – particularly solar and ICT equipment.
Low external noise levels and controlled indoor ambient noise levels	High external noise levels and uncontrolled indoor ambient noise levels

Table 5: Key design features affecting success of natural ventilation

Table 5 shows factors having the greatest impact on designing for natural ventilation, but the designer should also bear in mind that ventilation needs to provide good indoor air quality in both summer and winter, and in a controllable and energy efficient manner. Failure to be aware of these issues and focusing solely on one aspect can compromise a design.

For example, a design that focuses mainly on the avoidance of overheating i.e. summer design conditions and provides large openable windows may not allow for the fine control of ventilation required in winter to provide adequate draught free ventilation. In this case it may be better to install a separate ventilation opening to provide the winter ventilation requirement. Using large windows might also lead to lower air tightness, unless they are well sealed when closed, and may lead to draughts and infiltration energy loss.

Rules of Thumb at Concept Design

Height to Depth Ratios:

Single sided ventilation the depth of the room should not be more than 2.5 times the height of the room

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[35] ClassVent – link

Cross ventilation the depth of the room can be 5 times the height.

Minimum areas worst case summer ventilation:

Single sided ventilation - the opening area required is approximately 5% of floor area

Cross ventilation – the opening area required is approximately 2% floor area (1% on each side of the space)

Definitions and Notes

Opening

In the following text, and any examples, the areas referred to are those of an 'opening'. This may be a window but can equally be a ventilator, louvre or other such device.

Equivalent area

The area specified is the **equivalent area.** This is defined as *'the area of a sharp-edged orifice through which air would pass at the same volume flow rate, under an identical applied pressure difference, as the opening under consideration'.* In other words the area specified must take into account any significantly greater pressure drop resulting from acoustic treatment for example.

5.4.2 Scheme Design Stage

The development of the design beyond the concept stage allows a more detailed design of the proposed strategy for natural ventilation. The design tools are valuable at this stage as they enable the designer to carry out studies of the possible design solutions and calculate the likely provision of ventilation areas.

ClassVent Calculator

The *ClassVent* calculator available on the DfES indoor air quality website provides a means of sizing ventilation openings for natural ventilation design. The *ClassVent* ventilation design spreadsheet was prepared specifically to assist the scheme design stage. This is provided to make it easier for designers to meet Building Regulations requirements in common situations. The tool contains detailed user guidance notes which are also discussed briefly in this section. The spreadsheet was developed from the 'inverse openings' concept as explained in AM10[36]. The underlying calculations are based on the design methods contained in AM10 and the embedded equations for determining the flows are derived from BS 5925 and CIBSE A[37].

Note that equivalent area has been introduced into the Approved Document F and the ClassVent calculator instead of free area for the sizing of ventilators. Equivalent area is a better measure of the air flow performance of a ventilator. Free area is simply the physical size of the aperture of the ventilator but may not accurately reflect the airflow performance which the ventilator will achieve. The more complicated and/or contorted the air flow passages in a ventilator, the less air will flow through it. So two different ventilators with the same free area will not necessarily have the same air flow performance. A new European Standard, BSEN13141-1:2004, includes a method of measuring the equivalent area of background ventilator openings.

[36] Explain and reference

[37] Reference

The tool is tailored to a school classroom. The user needs to input basic information about the proposed classroom and the number of occupants, and the fresh air rate per person, to determine the required air flow. The user can then selects the design conditions by specifying temperature profile from the default:

- Winter
- Summer
- Mid-season.

Each design condition has an associated set of internal and external temperature conditions representing the likely summer and winter design conditions. The mid-season condition represents average conditions for the year. It is also possible to specify any design condition by selecting 'other' and entering a temperature profile.

From this basic data the spreadsheet calculates the area of ventilation openings required in each of the range of options indicated above. For each of the possible options the user can influence the design by changing the location of the openings on the façade under the chosen design. Although it is possible to select an approximate wind speed, at this stage of the design it is advisable to assume a calm day when the wind speed is zero.

The area and location of openings can be assessed and suitable ventilators provided to meet these requirements for each of the design options. It is important to note at this stage, that ventilation openings do not have to be windows. Whilst windows were traditionally used to provide ventilation they are not necessarily the most appropriate means of providing controllable and draught free air supply. A wide range of other ventilator options now exist with combinations of secure louvres, acoustic vents and motorised control units. These should be considered with the aim of producing a quiet, controllable, draught-free supply of fresh air.

It is probable that a single large openable window in the centre of the wall will not provide an adequate solution to the ventilation requirements of a modern classroom. It is likely that the design solution will be a combination of high level and low level vents with a central openable window for purge ventilation.

Some window types are inherently more controllable than others. For example sash windows, or sash windows combined with high level fanlight or hopper windows, are usually preferable to horizontal casement, central pivot or sliding windows which are all prone to draughts – see Section 6.

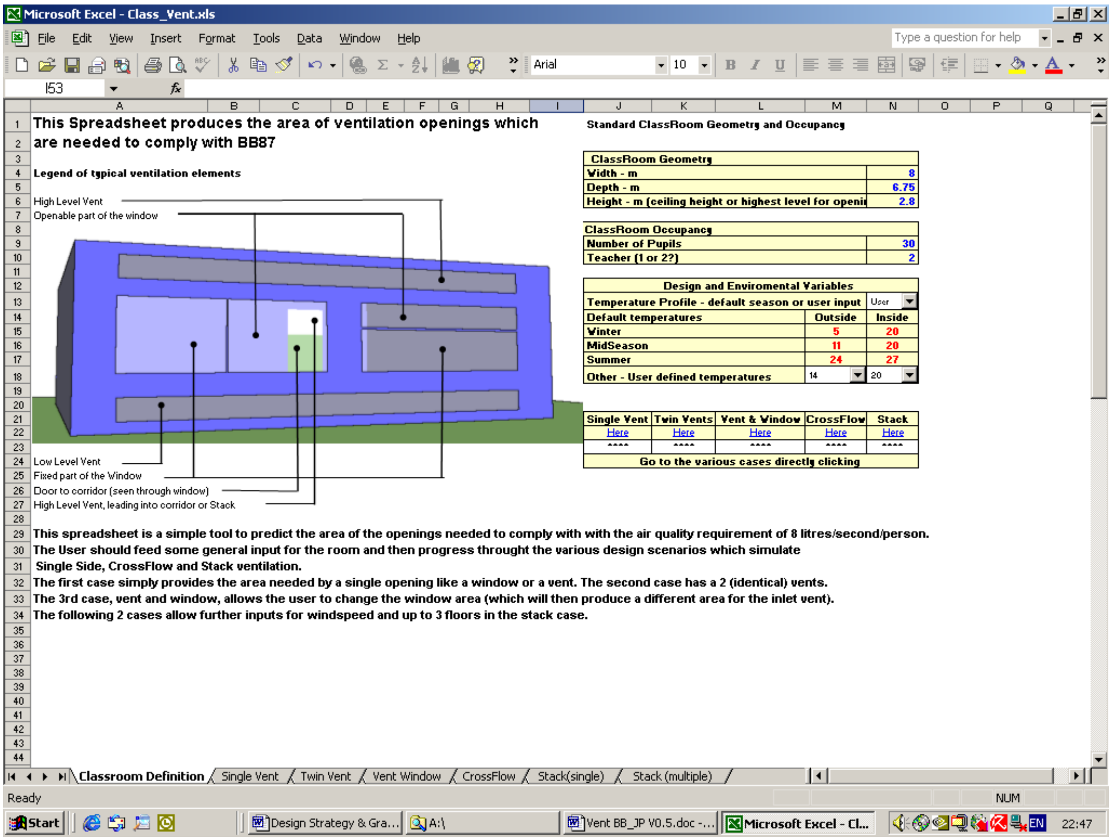


Figure 1 Image showing user ClassVent user-friendly interface

5.5 *Example Design Study*

The example below demonstrates the use of ClassVent to calculate the ventilation areas required to provide a given ventilation rate.

The following parameters are assumed for this case study:

- A standard classroom with a floor area of 54m^2 with 30 pupils and 2 adult occupants.
- The classroom meets the simple rule of thumb criterion (see section 5.41 above) for single sided ventilation
- A ventilation rate of 8l/s per person needs to be achieved.
- The periods of interest are winter, mid-season and summer. The internal and external conditions that represent these conditions should be selected for the region of interest. In this case the following have been chosen:

Period	External Temperature °C	Internal Temperature °C	Comment
Winter	5	20	Lower than average day-time external temperature
Mid-season	11	20	Typical mid-season external temperature
Summer	24	27	High external and internal temperatures to give worst case conditions.

Table 3 Assumed design conditions for example case study

5.5.1 Steady State Calculation of Area Requirements Using *ClassVent*

Entering this data into the *ClassVent* calculator allows assessment of the area requirements for various design strategies. The results for five design strategies (from a possible six) are shown in Table 6 below. Note that the results are based on zero wind speed.

Design condition	**Winter**		**Mid season**		**Summer**	
Design Strategy	Area 1 (m^2)	Area 2 (m^2)	Area 1 (m^2)	Area 2 (m^2)	Area 1 (m^2)	Area 2 (m^2)
Single sided - single opening	1.3	X	1.7	X	3.0	X
Single sided - equal area low and high level openings separation of 0.6 m	.8	.8	1.0	1.0	1.7	1.7
Cross flow - equal area openings same height - no wind	.9	.9	1.1	1.1	2.0	2.0
Cross flow - equal area openings 1m height separation - no wind	.6	.6	.8	.8	1.3	1.3
Opening with stack*	0.2	n/a	0.3	n/a	0.5	n/a

Table 4 ClassVent case study results for five design strategies at zero wind speed

*Note: stack height 5m, stack opening 1m^2

Table 6 shows that the areas required to provide adequate ventilation for indoor air quality under these temperature conditions, in the absence of the wind effect, varies from 0.2m^2 to more than 3m^2 depending on the strategy and design conditions. This indicates the need to carefully investigate the various design options at the earliest stages of design – to ensure that the façade can accommodate the areas required.
For any given strategy the area requirement changes by a factor of two between the summer and winter conditions; this necessitates provision of good control of installed vents as they must be capable of changing their areas over this range to give good control of the ventilation rate.

When the effect of wind speed is taken into account, this requirement is even more critical. For example, a cross flow ventilation, winter design would require two vents of 0.75m^2 in the absence of wind. The area requirement decreases to two vents of 0.22m^2 if a typical UK wind speed of 3m/s is assumed.

The beneficial impact of the wind speed can be seen on fourth design solution that has both stack effect and cross-flow potential and is typical of a clerestory type of design commonly used and can be a highly effective strategy. For example, with a wind speed of 3m/s the ventilation areas for summer conditions are approximately halved. Some designers choose to specify the areas based on a wind speed of around 1.5m/s as this provides a conservative estimate of the typical performance – very calm days are not common in the UK.

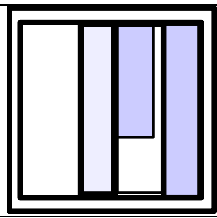
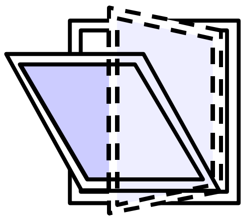
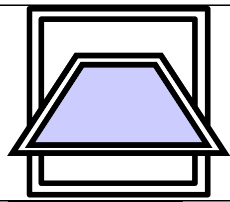
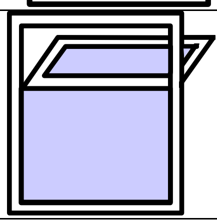
6 Examples of design options

Once the ventilation strategy has been selected and the size and location of the vents determined the type of vent opening needs to be chosen. For natural ventilation systems these fall into three types; windows, roof lights dampers, and louvres. All types of vent openings should be assessed against the criteria outlined below:

- Ventilation capacity – will the device provide the required air flow given the pressure available? This will depend on the way the vent opens and also for windows on the enclosing head, cill and jamb.
- Controllability – is the opening easily controlled by the occupant control? This is desirable, and window stays should be robust and adjustable.
- Security – is it secure for normal daytime use and night cooling if required? The risk of security problems of windows can be minimised by restricting the length or throw of stays or actuator arms.
- Sealing – will it be air tight when closed and is this durable? Aluminium framed windows are easier to seal than either steel or timber framed. Sealing of the latter two frames is particularly difficult if they are large.
- Vent actuators – can the actuators be combined with automatic systems? This should be considered with care to maximise potential performance.

6.1 Windows

Windows (together with doors and rooflights) have the advantage of being easily shut by the user and are easy to seal effectively. It is also possible to control most window designs automatically using actuators. Good window design is vital to ensuring effective natural ventilation; different window types have varying ventilation characteristics, acoustic properties and weather protection. Some of these features are described in table 7 below.

Window type	**Air flow**	**Ventilation control**	**Weather protection**	**Night ventilation**	**Comments**	
Horizontal sliding sash	Very good	Medium	Medium	Medium	No obstruction of internal blinds	
Tilt and turn	Good	Good	Good	Medium	Control is complex	
Centre pivot	Very good Medium	Medium	Good	Good	Can obstruct blinds and prevent glare control for VDU use and reflect noise into classroom.	
Bottom hung inward opening fan light	Medium	Good	Good	Very good	May obstruct blinds. Good noise control	

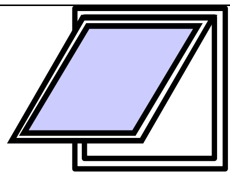
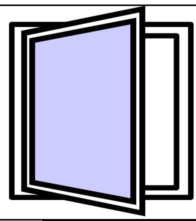
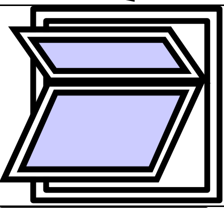
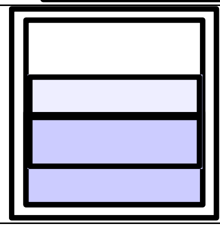
Top-hung outward opening	Good	Medium	Very good	Good	Can reflect noise into the room. Can pose a hazard if opening over a pathway or playground.	
Side-hung casement	Good	Medium	Medium	Poor	Poor security when open and rain can enter	
Upper fanlight and outward opening casement	Good	Very good	Very good	Very good	Good all round performance	
Vertical double sash	Very good	Good	Medium	Medium	No obstruction of internal blinds	

Table 5 Characteristics of different window designs

Horizontal pivot windows have a high ventilation capacity and the geometry promotes good distribution of supply air. Vertical pivot windows have similar characteristics to horizontal pivot windows but are vulnerable to driving rain. Interpane blinds may be needed as internal blinds are impractical.

Vertical sliding sash windows are a good design solution for schools as they allow a choice between high level ventilation alone or in combination with low level for increased stack effect. They do not intrude into the classroom and do not interfere with internal blinds. Sideways sliding sashes have some of these attractions but can lead to draughts at low level and can lack fine control of ventilation for occupant comfort. Sash windows also lend themselves to use in acoustic labyrinth windows where a wide gap between outer and inner windows provides an acoustically lined path for the air. (See BB93).

Top and bottom hung windows provide the same level of flexibility as vertical sash windows and can be used with a wide range of actuators. Bottom hung inward opening is useful for night cooling. For schools the most appropriate windows are probably top and bottom hung windows situated at high level and vertical sliding sashes.

Acoustic ventilators are available to improve the acoustic performance of a window – these can be fitted over window, above a transom or over the top of the window. It may also be possible to achieve the same effect as trickle ventilators through good window design (for example selected windows constantly open at very small opening angle).

When selecting a window design, it is important to consider security and health and safety risks. Centre or horizontal pivot windows can pose a hazard when at low level as building users can walk into them when they are open. However a suitable barrier such a planted border can be prevent people from walking into them.

It should be noted that window sills, reveals, internal and external blinds have a major impact on the effective area which is finally achieved. This is illustrated in figure 4 below. The comments in section 4.4 regarding fire safety should also be noted. Further guidance can be found in BS 5925: 1991 Code of practice for ventilation principles and designing for natural ventilation.

The performance of windows can also be compromised by the operation of windows in a way that was not intended by the designer. This can be avoided through proper consideration of practical, health and safety and control issues at the design stage.

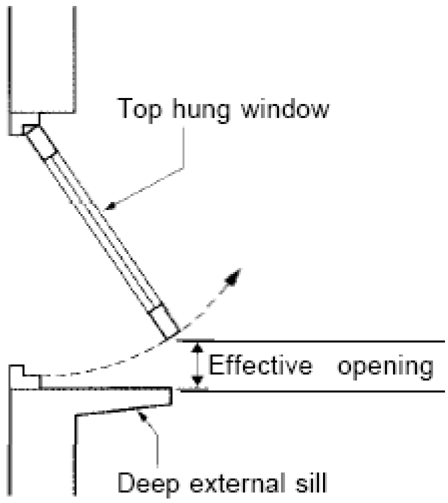


Figure 4 Effect of deep sill on effective window opening area

6.2 Dampers

Dampers are commonly used effectively in mechanical systems. In natural ventilation however they do not shut as tight as most windows and often have poor insulation standards resulting in condensation.

In natural ventilation systems they are usually used for air inlets below a false floor and at main exhaust points such as roofs. Standard blade dampers and sealed blade dampers are probably the most appropriate for use in natural ventilation systems.

6.3 Louvres

Louvres usually have glazed or aluminium blades. Fitting security bars inside their louvres enhances their potential for night cooling. Some glass louvres have good seals but should these be carefully selected and checked for construction and performance. Acoustic louvres or conventional weather louvres backed by sound attenuators can also be used. Centre pivot louvres provide improved airflow compared with single flap systems. Small louvres with little projection into space can avoid clash with internal blinds. Louvres are available that can be controlled automatically and linked to the building management system.

6.4 Roof ventilators

Roof mounted wind and stack ventilators are also available; wind from any direction strikes louvres on the ventilator and is channelled down into the occupied space. At the same time warm air rises up and is exhausted from the building on the down-wind side of the ventilator. These may be suitable where external noise and security issues preclude the use of openable windows and where air at high level is cleaner than that at ground level. They also provide good night time cooling.

Roof mounted terminals offer a number of advantages over other methods of providing fresh air in schools and their use is now becoming common. Experience suggests that they offer a combination of good ventilation and acoustic separation from external noise. They are generally adopted for single storey applications but two storey schools have used them successfully.

Some research suggests that these devices may not be effective on still days[38] and therefore they are usually used in conjunction with other vents such as:

- Openable windows
- Ducted air supply bringing fresh air in at ground level schools with more than one storey
- Dampers to control the fresh air supply in response to internal and external conditions
- Fan assisted extract to provide additional air movement when the internal temperature is high.

The detailed specification is best left to the makers who have performance curves for all of their products.

6.5 Background trickle vents

Trickle vents can be integral to the window frame, part of the glazed unit or independent of the window. However, they will not provide the minimum fresh air rate required during occupancy but can provide a very limited supply of fresh air out-of-hours.

Studies into the effectiveness of trickle vents in classrooms suggest that in 'mid-year' conditions, a single sided ventilation strategy, with four trickle vents each with free area of 4000mm^2 i.e. 16,000mm^2 of free area provided by inlets and outlets of 8,000mm^2 vertically separated by 2m will not provide adequate ventilation to ensure satisfactory indoor air quality for the occupants.

Trickle type ventilators are available which are wind limited and 'throttle down' according to pressure difference across the ventilator to reduce draught risks during windy weather. This is a desirable feature but they should be fitted with a manual control so that they can be adjusted to provide a lower ventilation rate in less airtight buildings.

6.6 Other openings and approaches

It is common to use combinations of opening types in an overall design. For example motorised dampers or louvres might supply fresh air to an under-floor plenum and air might be exhausted from high-level windows. Combinations of window types in one unit might also be useful; for example a hopper (the top panes are pivoted horizontally to open inwards) over a centre pivot window allows night ventilation and air to occupants deep in the room, whilst the centre pivot allows high summer ventilation rates.

6.7 Actuators

Actuators provide an automatic means of controlling vent openings. It is best, as a general rule, to have one actuator per ventilator. The type of actuator suitable depends on a number of factors, such as the location of the vent and manner of opening; the weight and size of vent; the travel and free area to be achieved; available space and smoke ventilation. The types of actuators commonly used for natural ventilation are:

- Linear push-pull piston actuators
- Projecting chain drive push-pull actuators
- Rack and pinion actuators

[38] Report by J A Crabb, 1999 (was this published?)

- Linear sleeved cable or rod actuators: often visually intrusive and cumbersome, may be used in some Victorian schools.

7 Control of Ventilation

7.1 Introduction

It is important that ventilation is controllable to maintain reasonable indoor air quality and to avoid waste of energy. Schools have traditionally been provided with local manual control by the occupants and this is recognised as being favoured by most building occupants – provided it is readily controlled and does not compromise thermal comfort. However, one disadvantage of user-controlled windows appears to be that teachers are reluctant to open them because of possible noise, heat loss and security risks.

7.2 Occupant Control

The occupants will need to be able the ventilation whatever system is used. For example, activities in the classroom or unplanned spillages of odorous materials may require swift and copious purge ventilation. This aspect of ventilation will be closely linked to the ventilator provided or the window selection. Some ventilators incorporate a simple flap that allows users to shut or open the ventilation provided depending on internal and external conditions.

To ensure that controls are within reasonable reach of occupants it is recommended that they are located in accordance with the guidance for Requirement N3 *Safe opening and closing of windows etc*. which is given in paragraph 3.2 of Approved Document N (1998 edition). The use of pull cords, operating rods, or similar devices may help to achieve this. These controls can either be manual (i.e. operated by the occupant) or automatic.

7.3 Automatic Control

School design is now much advanced and it is reasonable to consider the use of an automatic natural ventilation system together with CO_2 sensing. Given the inherent benefits of natural ventilation, when it provides the equivalent predictability of indoor air quality as a mechanical system, it is important that the designer fully explores its potential. The adoption of the performance standard approach to ventilation as described in Section 1 lends itself to the use of an automatic control system using CO_2 sensing, and possibly temperature control to provide night cooling control and to limit excessive heat loss in winter.

Sophisticated building management control systems are now available an their use is becoming widespread and less costly. Using this technology, together with sensors located within the building, (eg, local passive infra-red detectors or CO_2 concentration sensors as an indicator of indoor air quality occupancy level) it is possible to give precise control over the ventilation of the school. The control can also be linked to and external weather stations to modify the openings depending on outside weather conditions

This approach has been used in schools in England and Wales (and in Europe) and provides good indoor air quality with minimum excess ventilation. It also ensures that compliance with the performance standard is being achieved as the BMS can record CO_2 levels throughout the day.

It is important that any window and ventilator operating mechanisms are virtually silent as even if they are of low noise their intermittent operation can cause serious disturbance to class activities if they are audible. Silence is achieved by incremental actuators. It is best if these can be over-ridden by the teacher to provide purge ventilation when required.

8 Control of Summertime Overheating – Section under development

One of the main design problems faced by the designers of modern schools is the prevention of overheating. Classrooms can be subject to substantial heat gains from electrical equipment, the pupils and from solar gain. Electronic white board projectors and overhead projectors are in use for a large part of the school day in some schools. When in use, blinds are often drawn to provide easier vision of the board and this again increases the heat load from the electric lights.

These internal gains, which provide useful heat in the heating season, can lead to overheating in the summer and therefore should be reduced as much as possible by selection of efficient appliances with low heat rejection. Energy labelling schemes for domestic equipment, such as personal computers, cookers and other kitchen equipment, fridges, and washing machines, indicate bands of energy efficiency. Selecting band A and B rated equipment will reduce energy consumption. If less efficient equipment is used then other elements of the building must be improved to compensate for the increased equipment loads. In particular, summertime overheating may result from excessive heat gains from inefficient equipment. Additional information on the efficiencies of equipment can be found from the following websites:

> www.ukepic.co.uk - UK Environmental Product Information Consortium
> www.mtprog.co.uk - Market Transformation Programme
> www.sedbuk.com - Boiler efficiency database

In addition to ensuring that all internal gains are reduced to a minimum it is necessary to control solar gains. For those sensitive areas that cannot be oriented to the north, some form of solar shading may be required - either using special glass or blinds or a combination of the two.

The first means of removing the unwanted heat is by natural ventilation. The ventilation rate for cooling in summer is significantly more than that required for the hygiene of the occupants. Therefore, particular consideration should be given to the design of the building so that natural ventilation can achieve these supply rates.

Deep plan spaces should be avoided and classrooms should have the provision for cross-ventilation. As the worst situation is likely to be at times of high solar radiation it may be possible for the ventilation to be driven by a solar induced stack effect - solar chimneys are one way to utilise this effect. This will encourage ventilation on days with little or no wind. It may be useful to supplement the natural ventilation with fan assistance in a hybrid system for those times when the design requirements (either for fresh air for IAQ or reduction of internal temperatures) are not being met.

An undesirable rise in temperature during warm weather can be caused by uncontrolled incidental and solar heat gains, or by high densities of occupation, eg in lecture rooms. In these circumstances sufficient natural ventilation is particularly important. Mechanical ventilation may be necessary in some instances to help to control air temperature and sometimes cooling may be required.

Reflective, white or very light roof surfaces reduce the solar heat gain through roofs as well as reducing the thermal stress in weatherproof coverings, but will tend to become less effective without adequate maintenance. Insulation in the roof and walls also helps to reduce this solar gain, but will also reduce the ability of the excess heat to escape from the space. Increased thermal mass in the conditioned space controls the degree of temperature swing.

Excessive solar heat gain through windows can be minimised by appropriate orientation and by the use of brise soleil structural shading, louvres, blinds and curtains. Shading the glass from the outside is the most effective method of control. However, this calls for careful design of sun shading devices to avoid impairing the daylighting and ventilation of a classroom.

Incidental heat gains (eg solar, teaching equipment and light fittings) will contribute heat to the space. Allowing for these and designing suitably responsive controls and heating systems will help to reduce fuel consumption. With the increasing use of Information Communication Technology (ICT) in schools these incidental gains become increasingly significant and may require special consideration. Heat gain from ICT equipment can be minimised by selecting energy efficient equipment; LCD monitors and laptops drastically reduce heat gains compared to conventional CRT monitors.

Solar gains can be beneficial if careful consideration is given to the design and orientation of the building, but excessive solar gains may lead to overheating. Windows on a south-east facing facade will allow entry of sunlight early in the morning but will avoid direct sunlight during midday and early afternoon when the solar radiation is more intense. West and south-west facing glazing leads to the greatest risk of overheating.

Passive methods of cooling should be used as far as possible to avoid the use of air conditioning. Summertime overheating can be largely eliminated by the provision of sufficient thermal mass. This can conflict with requirements for acoustic absorption but there are ways of providing both thermal mass and acoustic absorption; for example acoustic baffles are available which can be hung from the ceiling which do not prevent the use of the thermal mass of the building structure.

Using boreholes as a source of cooling for air conditioning of a school becomes an economic and energy efficient possibility as boreholes give very high coefficients of performance for cooling energy which will benefit the whole building energy calculation greatly.

Earth tubes and thermal labyrinths can also be very useful in tempering supply air to teaching areas. With careful design using earth tubes or thermal labyrinths to temper the supply air it is theoretically possible with a super-insulated school for there to be no net heat demand and boiler sizes will be very small. Earth tubes and thermal labyrinths also provide good sound attenuation.

Thermal insulation of roofs beyond Part L requirements has an advantage in preventing summertime overheating and can be built into a roof structure capable of preventing the penetration of rain noise through the roof structure.

The summertime overheating criteria should not be too strict in temperature terms. A criterion which changes with external conditions is probably best. We propose the following performance standard for summertime conditions which allows higher temperatures when the outside air temperature is higher. This takes advantage of the ability for people to adapt to temperature changes. This temperature adaptation is well documented. It is not sensible to require the same maximum internal temperature whatever the outside conditions as this makes no allowance for human adaptation to hot temperatures.

[YUN1]Get this specified more precisely