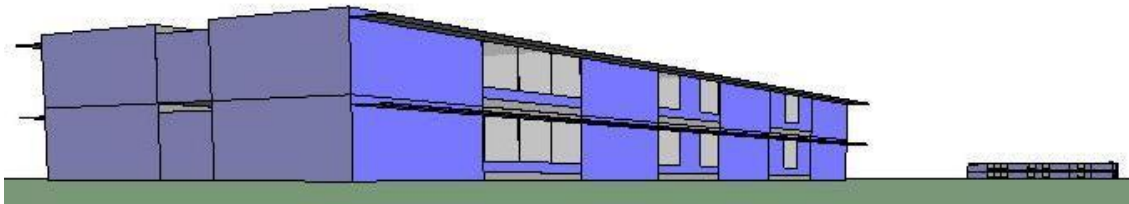


Building Bulletin 101

Ventilation of School Buildings



Regulations
Standards
Design Guidance

Version 1.4 – 5th July 2006

ISBN 011-2711642

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1 Regulations for school buildings

1.1 Introduction

This Building Bulletin provides the regulatory framework in support of the Building Regulations for the adequate provision of ventilation in schools. It deals with the design of school buildings to meet the ventilation requirements of both The School Premises Regulations¹ and the Building Regulations Part F (Ventilation)². This Building Bulletin is quoted in Approved Documents F and L2 (amended 2006) as a means of compliance with Regulations F1 and L of the Building Regulations for school buildings.

1.2 Part F of the Building Regulations

Part F of the Building Regulations applies to 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.”

Approved Document F (ADF) provides recommended means of compliance with this requirement. It 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 may be achieved by providing a ventilation system which:

- a. extracts, before it is generally widespread, water vapour from areas where it is produced in significant quantities (e.g. kitchens, utility rooms and bathrooms);
- b. extracts, 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 dilutes, when necessary, pollutants and water vapour produced in habitable rooms, occupiable rooms and sanitary accommodation;
- d. makes 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;
- e. is designed, installed and commissioned to perform in a way which is not detrimental to the health of the people in the building; and
- f. is installed to facilitate maintenance where necessary.

For Schools and educational buildings, it explicitly states:

¹ Statutory Instruments: 1999: 2. The Education (School Premises) Regulations 1999: Education, England & Wales.

London: The Stationery Office. ISBN 0110803310. - www.legislation.hmso.gov.uk/si/si1999/19990002.htm

Note that the Education (Schools Premises) Regulations apply to LEA maintained schools. Independent schools are covered by Statutory Instruments: 2003:

No. 1910. The Education (Independent School Standards) (England) Regulations 2003, London: The Stationery Office, ISBN 0110471008

The Education (Independent School Standards) refer to the Schools Premises Regulations for guidance on ventilation.

² Department for Communities and Local Government: The Building Regulations Approved Documents F, Ventilation. <http://www.odpm.gov.uk/index.asp?id=1164179>

Ventilation provisions in schools can be made in accordance with the guidance in DfES Building Bulletin 101, Ventilation of School Buildings (see www.teachernet.gov.uk/iaq) and in the Education (School Premises) Regulations. Building Bulletin 101 can also be used as a guide to the ventilation required in other educational buildings such as further education establishments where the accommodation is similar to that found in schools, for e.g. sixth form accommodation. However, the standards may not be appropriate for particular areas where more hazardous activities take place than are normally found in schools, e.g. some practical and vocational activities requiring containment or fume extraction.

The Building Bulletin can also be used for children's centres and other early years settings, including day nurseries, playgroups, etc.

1.3 School Premises Regulations

The current School Premises Regulations (SPR) quoted below 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:

- (1) All occupied areas in a school building shall have controllable ventilation at a minimum rate of 3 litres of fresh air per second for each of the maximum number of persons the area will accommodate.
- (2) All teaching accommodation, medical examination or treatment rooms, sick rooms, isolation rooms, sleeping and living accommodation shall also be capable of being ventilated at a minimum rate of 8 litre of fresh air per second for each of the usual number of people in those areas when such areas are occupied.
- (3) All washrooms shall also be capable of being ventilated at a rate of at least six air changes an hour.
- (4) Adequate measures shall be taken to prevent condensation in, and remove noxious fumes from, every kitchen and other room in which there may be steam or fumes.

1.4 Recommended ventilation performance standard for teaching and learning spaces

In addition to the general ventilation requirements repeated from ADF in Section 1.2 above, the following school specific recommended performance standard applies to teaching and learning spaces:

Ventilation should be provided to limit the concentration of carbon dioxide in all teaching and learning spaces. When measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of carbon dioxide should not exceed 1500 parts per million (ppm).

This is based on the need to control carbon dioxide resulting from the respiration of occupants. In teaching and learning spaces, in the absence of any major pollutants, carbon dioxide is taken to be the key indicator of ventilation performance for the control of indoor air quality.

1.5 Ventilation provision

In addition to the requirement to meet the CO₂ performance standard stated above in Section 1.4 it is recommended that the design should also meet the following advisory performance standards that reflect the needs of the School Premises Regulations and the recommendations of the Health and Safety Executive.

- (i) The maximum concentration of carbon dioxide should not exceed 5000 ppm during the teaching day.
- (ii) At any occupied time, including teaching, the occupants should be able to lower the concentration of carbon dioxide to 1000 ppm.

The following ventilation rates would in normal circumstances meet the required CO₂ performance standard given in Section 1.4 and these additional recommended standards. The ventilation levels specified in this section may not, however, be suitable for areas used for special activities, such as science laboratories and food technology rooms etc. The guidelines in Section 2 should be applied to these areas.

1.5.1 Natural ventilation for teaching and learning spaces

Purpose-provided ventilation (i.e. controllable devices to supply air to and extract air from a building) should provide external air supply to all teaching and learning spaces of:

- a minimum of 3 l/s per person (litres per second per person), and
- a minimum daily average of 5 l/s per person, and
- the capability of achieving a minimum of 8 l/s per person at any occupied time. Additional ventilators could be used to provide this extra ventilation e.g. supplementing windows with the addition of louvres or stacks. This ventilation may not be required at all times of occupancy, but it should be achievable under the control of the occupant. When fresh air is supplied at a rate of 8 l/s per person, the carbon dioxide concentration will generally remain below 1000 ppm.

These flow rates should be based on the maximum number of occupants likely to occupy the space, and should be achieved under the design conditions indicated in Section 6.

The Department for Education and Skills has provided the ClassVent³ calculator to be used with Building Bulletin 101 that enables a designer to rapidly calculate areas for airflows into and out of a classroom. Designs using the ClassVent calculator (see Section 6) could be deemed to satisfy the guidance given in this section. Other design tools can also be used, but calculations for these designs would need to be submitted for building control approval.

1.5.2 Mechanical ventilation for teaching and learning spaces

If a mechanical ventilation system is specified, it should be commissioned to provide a minimum daily average of 5 l/s per person. In addition, it should have the capability of achieving a minimum of 8 l/s per person at any occupied time.

³ DfES (2006) ClassVent - www.teachernet.gov.uk

1.5.3 Additional Issues

These are the performance standards that are required for good indoor air quality and means of achieving these have been given above for natural and mechanical ventilation solutions. However, the designer has the freedom to use whatever ventilation provision suits a particular building, including innovative products and solutions, if it can be demonstrated that they meet the performance standards given in 1.4 and 1.5.1.

Note that in most circumstances these ventilation rates will not be adequate to remove significant amounts of thermal gains that may lead to overheating and therefore higher ventilation rates may be needed. Section 8 gives the recommended standards for compliance with Building Regulations Part L for the avoidance of summertime overheating. Building Bulletin 101 is quoted in Approved Document L2A as recommended means of compliance with Part L for the avoidance of summertime overheating. The ClassCool tool assists with providing suitable design solutions for standard classrooms and can be used for compliance purposes. For other spaces, such as libraries and halls other means of assessing overheating may be required as ClassCool is not suitable for these types of spaces.

1.5.4 Office accommodation

For office accommodation, in the absence of tobacco smoke or other excessive pollutants, a supply rate of 10 l/s per person is recommended. This outdoor air-supply rate is based on controlling body odours and typical levels of other indoor-generated pollutants. Further guidance on the ventilation of office accommodation using natural or mechanical means is given in Approved Document F.

1.6 Acoustic standards – designing to meet the Building Bulletin 93 indoor ambient noise levels

This section clarifies the guidance for acoustic performance in Building Bulletin 93 (BB93) ⁴. Naturally ventilated schools are required to meet the 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; this is now superseded and the definitive guidance is as follows:

For the Minimum Fresh Air Supply Rate of 3 l/s per person, the design should achieve the performance standards for the indoor ambient noise levels in Table 1.1 of Building Bulletin 93. 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 5 dB $L_{Aeq,30min}$.

⁴ Department for Education and Skills (2003). Acoustic Design of Schools, A Design Guide, Building Bulletin 93.

London: The Stationery Office. ISBN 0 11 271105 7 - www.teachernet.gov.uk/acoustics

⁵ Building Bulletin 93 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.

For classrooms designed specifically for use by hearing impaired students and for speech therapy sessions the performance standards in Table 1.1 of BB93 should be met at both ventilation rates.

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 indoor ambient noise level requirements should be possible because there is flexibility for lower noise levels during occupied periods at a ventilation rate of 3 l/s per person and higher permissible levels at a higher ventilation rate of 8 l/s per person.

In addition, but at the discretion of the teacher, when the classroom is occupied higher noise levels may be acceptable when higher rates of ventilation than 8l/s per person are required – for example during overheating on hot summer days when it may be necessary to open all the windows.

1.6.1 Alternative acoustic performance standards

It is recognised that the acoustic needs of classrooms are stringent and may prevent the use of natural ventilation in some circumstances, even given the suggested addition of 5 dB to the requirements when providing external air at a rate of 8 l/s per person. Consequently, the designer is advised to refer to section 1.2.1 of Building Bulletin 93 quoted below.

1.2.1 Alternative performance standards

In some circumstances, alternative performance standards may be appropriate for specific areas within individual schools for particular educational, environmental or health and safety reasons. In these cases, the following information should be provided to the Building Control Body:

- *a written report by a specialist acoustic consultant, clearly identifying:*
 - (a) all areas of non-compliance with BB93 performance standards;*
 - (b) the proposed alternative performance standards; and*
 - (c) the technical basis upon which these alternative performance standards have been chosen.*
- *written confirmation from the educational provider (e.g. school or Local Education Authority) of areas of non-compliance, together with the justification for the need and suitability of the alternative performance standards in each space.*

Individual specialist acoustic designers will be able to advise on the necessary acoustic performance of the building envelope, which may involve some fine tuning of the performance standards quoted in BB93. The appropriate alternative performance standards will inevitably vary with the type of background noise and the type of activities carried out in the teaching or learning space.

The aim of quoting this statement of ‘alternative performance standards’ for the acoustic requirements in this Building Bulletin on ventilation, is to allow some flexibility so that the ventilation requirements of schools can be met by natural means, wherever it is possible to maintain a level of acoustic performance that is deemed appropriate by the users of the school. It is intended that this will lessen the likelihood of an unwanted mechanical ventilation system being installed, incurring unnecessary capital and running costs.

1.7 Performance standard for the avoidance of overheating

Three parameters have been developed which indicate when overheating is likely to be problematic. These standards apply outside the heating season and are for the occupied period of 09:00 to 15:30, Monday to Friday, from 1st May to 30th September.

- the number of hours for which a threshold temperature is exceeded
- the degree to which the internal temperature exceeds the external temperature
- the maximum temperature experienced at any occupied time.

These performance parameters will ensure that the design of future schools is not dictated by a single factor as previously but by a combination of factors that will allow a degree of flexibility in the design of the school. They will also take account of the use of the school, for example in their choice of term dates.

The performance standards for summertime overheating in compliance with Approved document L2 for teaching and learning areas are:

a) There should be no more than 120 hours when the air temperature in the classroom rises above 28°C

b) The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on average)

c) The internal air temperature when the space is occupied should not exceed 32°C.

In order to show that the proposed school will not suffer overheating two of these three criteria must be met.

In order to assist in determining possible overheating in classrooms as indicated by these performance parameters, the ClassCool tool has been published by the DfES. The ClassCool results are presented in terms of the above performance parameters and would demonstrate compliance with the performance standards.

Note that other appropriate tools for predicting the required parameters can be used and if so should use the geographically closest CIBSE Test Reference Year and be analysed according to the guidance given in Section 8.4.2.

Note: the overheating criteria are for the thermal comfort of occupants and are not applicable for equipment such as server rooms.

1.8 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 local-authority-maintained schools and independent schools: and to other educational buildings such as further education establishments, where the accommodation is similar to that found in schools, for example, sixth form accommodation and lecture theatres. It also applies to children's centres and other early years settings including day nurseries etc.

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, prefabricated buildings commonly referred to as 'temporary' buildings that are normally in place for

longer than 28 days are therefore subject to the Building Regulations. However, the Building Regulations do permit some relaxation of this requirement when buildings that were designed to a previous version of the Building Regulations are relocated.

1.9 Work on existing buildings

When a building undergoes a material change of use, as defined in the Building Regulations Part F ⁶ the guidance in this document applies to the building, or that part of the building, which has been subject to the change of use. For example, conversion of an office building or factory into a school building would constitute a material change of use.

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. It is recognised, however, that it would be uneconomic to upgrade all existing school buildings to the same standards as new school buildings.

The Building Regulations define windows as a controlled fitting and, therefore, when windows in an existing building are replaced, the work should comply with the requirements of Building Regulations Parts L and N. Also, after the building work, compliance with other applicable parts of Schedule 1 (Parts B, F and J) should be at the same level or better than it was prior to the work.

Any new windows should therefore allow at least as much air infiltration as the old windows that are replaced. Therefore as the new windows will be more airtight all replacement windows must include controllable ventilation openings.

Unless the room is ventilated adequately by other installed ventilation provisions, all replacement windows should include trickle ventilators, preferably with accessible controls. Alternatively, an equivalent ventilation opening should be provided in the same room. In all cases, the ventilation opening should not be smaller than was originally provided, and it should be controllable.

Where the original windows included trickle ventilators, the replacement windows should at least make allowance for this by providing an equivalent controllable ventilation opening of an area no smaller than the original. However, where it is likely that the trickle ventilators would have provided inadequate ventilation, options for upgrading the ventilation during window replacement should be considered. It should not be assumed that sufficient ventilation will be achieved by replacing window ventilators with larger capacity ventilators; cross ventilation may be required.

FENSA ⁷ operates a self-certification scheme for windows and can confirm whether the proposed ventilation provision complies with Approved Document F.

⁶ Office of the Deputy Prime Minister (2000). Statutory Instrument 2000/2531 The Building Regulations, London: The Stationery Office. ISBN 0 11 099897 9
- www.opsi.gov.uk/si/si2000/20002531.htm

⁷ www.fensa.co.uk

2 Ventilation of special areas or buildings

In addition to the requirements for teaching and learning spaces set out in section 1 of this document, the ventilation requirements of a number of other specialist areas need particular consideration. Some of these special areas are dealt with in the following sections.

2.1 Practical spaces

The ventilation of all practical spaces 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 of the whole space can be provided to prevent the build-up of pollutants.

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. In this case local exhaust ventilation may be considered to be necessary following a risk assessment carried out under the Control of Substances Hazardous to Health (COSHH) Regulations 2002⁸. Local exhaust ventilation may be needed (according to BS 4163⁹) for the following applications:

- 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
- work undertaken with plastics and glass reinforced plastics (GRP)

The use of bunsen burners in laboratories will not generally require any additional ventilation provision and attention should be paid to the Gas Safety (Installation and Use) Regulations 1998, Regulation 2 (6)(b).

Fume cupboards may be needed in some laboratories and preparatory 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. This 'make-up' air may need to be heated in order to maintain adequate internal conditions.

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

⁸ Health and Safety Executive, Control of Substances Hazardous to Health (COSHH) Regulations 2002 - www.hse.gov.uk/coshh

The Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS)¹⁰ produces risk assessments for pollutants commonly used in science and design technology. The CLEAPSS Model Risk Assessments for Design and Technology define ventilation needs for many design and technology processes. The CLEAPSS hazcards specify a 'well-ventilated room' for science labs (5 air changes per hour would be considered as "well-ventilated") see Section 2.5. 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 when handling chemicals.

Fans and ventilation systems specifically installed to remove hazards (e.g. fume extractor and fume cupboards) 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:

Health and Safety Executive (1993) *Introduction to Local Exhaust Ventilation, HS(G) 37*, London: HSE Books. ISBN 0 11 882134 2 - www.hsebooks.com/Books

Health and Safety Executive (1998) *Maintenance, Examination and Testing of Local Exhaust Ventilation, HS(G) 54*
London: HSE Books. ISBN 07176 1485 9

Health and Safety Executive (2003) *COSHH Essentials Easy Steps to Control Health Risks from Chemicals, HS(G) 193* - www.coshh-essentials.org.uk

Industrial Ventilation: A Manual of Recommended Practice, 24th Edition, American Conference of Government Industrial Hygienists - www.acgih.org

British Standards Institute (2000) *BS 4163 Health and Safety for Design and Technology in Schools and Similar Establishments – Code of Practice (AMD 11025)*
London: British Standards Institution Bookshop

2.2 Information communication and technology (ICT) suites

Natural ventilation should be used for standard teaching and learning areas with limited computer equipment. Building Bulletin 87 (BB87) suggests that a 'typical' classroom will have up to five desktop PCs, a laser printer and an overhead projector (OHP)/computer projector. Heat gains from ICT may be useful in the heating season, but can lead to overheating in the summer. Heat gains can be minimised by selecting energy-efficient appliances with low heat rejection¹¹. If less efficient equipment is used, other elements of the building can be improved to compensate for the increased equipment loads.

In classrooms with more than the typical provision of ICT equipment, mechanical ventilation and comfort cooling may be considered, providing other passive means of maintaining thermal comfort have been thoroughly investigated.

⁹ British Standards Institute (2000) *BS 4163 Health and Safety for Design and Technology in Schools and Similar Establishments – Code of Practice (AMD 11025)*, London: British Standards Institution Bookshop

¹⁰ The Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS) - www.cleapss.org.uk

¹¹ A database of energy efficient ICT equipment is available on the Energy Star website: www.eu-energystar.org/en and further information is available in factsheet GIL116 Information communication and technology equipment in schools available from The Carbon Trust.

It may be possible to avoid overheating of ICT suites through good natural ventilation system design with the appropriate thermal construction and measures to minimise solar gains. With an appropriate control strategy, for most of the year, mechanical ventilation may not be needed. Passive cooling methods can accommodate most ICT loads and should be used in preference to mechanical cooling.

The Building Regulations F1 requirement for computer rooms can be met by following the guidance in CIBSE B2: 2001, Section 3.9¹².

2.3 Food technology

This section covers food technology areas dedicated to teaching and demonstration; it does not cover catering kitchens. 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 with local extract fans and with 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 reasonably cool conditions.

For guidance on ventilating catering kitchens see the following publications:

Health and Safety Executive (2000), *Catering Information Sheet No 10*
www.hse.gov.uk/pubns/cais10.pdf

Health and Safety Executive (2000), *Catering Information Sheet No 11*
www.hse.gov.uk/pubns/cais11.pdf

2.4 Hot metal equipment

Where provision must be made for hot metal work, local exhaust ventilation for fumes should be provided for all equipment. Additionally, where the heat source is provided by gas, 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 levels can be elevated by the use of Bunsen burners; in a class of 30 pupils, CO₂ from Bunsen burners can be more than twice as high as that from respiration. However, there is no requirement to provide extra ventilation air for combustion (see Section 2.1).

Where natural ventilation cannot be relied upon to provide the necessary ventilation, mechanical ventilation might be needed. Local exhaust ventilation is usually required in science laboratories where chemical experiments are conducted to allow for the possibility that 30 pupils might conduct chemical experiments at any given time. Heat recovery on local extract fans and on supply-and-

¹² CIBSE (2001) *Guide B2, Ventilation and Air Conditioning, Section 3.9 'Computer rooms'*, CIBSE Bookshop www.cibse.org

extract systems is recommended to minimise ventilation heat losses. Partially opening windows are useful for natural ventilation when chemical experiments are not being conducted.

However, problems from emissions and heat gains are likely to be intermittent rather than continuous, so some form of boost ventilation is preferable. The CLEAPSS¹⁰ risk assessments for pollutants (including carbon dioxide) generated by science experiments conducted in a typical open laboratory assume 5 air changes per hour (this supersedes the 2 ach previously quoted by BB88 - Fume Cupboards in Schools).

Fume cupboards should be installed and operated in accordance with the guidance in Building Bulletin 88¹³. 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.

Preparation rooms usually adjoin science labs and tend to suffer from inadequate ventilation. Often they are used to store chemicals, but regardless of this, CLEAPSS suggests a ventilation rate of 5 ach 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 2 ach 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.

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 should consider the fabric construction, its thermal conductivity (U-values) and permeability to water vapour. Calculated predictions of interstitial condensation will be needed to match the ventilation to the fabric performance.

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 particularly dependent on the relative humidity and air movement. 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 to extend the life of decorated surfaces. Design guidelines for swimming pools are as follows:

- The ventilation system should provide a minimum fresh-air rate of 12 l/s per person.
- A guideline ventilation rate of 10 l/s 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 the pool hall and the changing rooms will help prevent moisture permeating the building structure.

13 Department for Education and Employment (1998). Fume Cupboards in Schools, Building Bulletin 88., London: The Stationery Office. ISBN 0112710271
- www.teachernet.gov.uk

- 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 to set the plant to start up occasionally on low speed out of school hours.
- Pool-hall air temperature should be 1°C above pool-water temperature, except in the case of hydrotherapy pools and warm-water pools where the air temperature should be cooler than the water temperature.
- Air temperatures should not generally exceed 30°C and relative humidity should be about 50% - 70%.
- The maximum recommended pool water temperatures are as follows:
 - Competitive swimming and diving, training and fitness swimming: 27°C.
 - Recreational use, conventional main pools and adult teaching: 28°C.
 - Children's teaching, leisure pools: 29°C.
 - Babies, young children, disabled: 30°C.

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, such as 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°C - 25°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, evaporation of the chemical products of the water treatment process (e.g. chloramines) from the pool surface is inhibited. After removing the cover, sufficient time should therefore be allowed for these concentrations to reduce to acceptable levels before

pool use. It is also important to allow for cleaning of pool covers to prevent the build-up of contaminants on the cover.

Further reading:

Sports Council (1994) *Small Public Indoor Pools*
www.sportenglandpublications.org.uk/asp/home.asp

Perrin GA, (1980) *Sports Halls and Swimming Pools: A Design and Briefing Guide*
ISBN 0 4191 1140 9, London: Spon

Swimming Pool Water: Treatment and Quality Standards: ISBN 0 951 7007 66
<http://www.pwtag.org/home.html>

Sports Council (1996), *Handbook of Sports and Recreational Building Design, Volume 3: Ice rinks and swimming pools*, Edited by Geraint John and Kit Campbell, 2nd Edition, ISBN 0-7506-2256-3, Oxford: Butterworth Heinemann

Publicly Available Specification PAS39:2003 Management of public swimming pools - Water treatment systems, water treatment plant and heating and ventilation systems - Code of practice. From 020 8896 9001 or orders@bsi-global.com

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*¹⁴. These are summarised in **Table 1** below.

Guidance for accommodating pupils with special educational needs and disabilities in mainstream schools is specified in 'Building Bulletin 94: Inclusive School Design: Accommodating Pupils with Special Educational Needs and Disabilities in Mainstream Schools'¹⁵. 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.

2.7.1 Cross-infection

Children in special schools may be vulnerable to infection, therefore, it is essential that infection-control policies should be in place and implemented. Managing cross-infection is a complex subject, but the risks of cross-contamination can be reduced through adequate source control and by taking the measures below:

- Hygiene areas, toilets, shower areas, cleaner's rooms, areas holding soiled clothes or clinical waste and laundry should be mechanically ventilated and slightly negatively pressurised relative to adjacent spaces. This also assists odour control.
- Recirculation of air, within areas occupied by pupils, by ventilation, air conditioning or heating systems 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

¹⁴ Department for Education and Employment (1992). *Designing for Pupils with Special Educational Needs: Special Schools*, Building Bulletin 77. London: The Stationery Office. ISBN 0112707963.

¹⁵ Department for Education and Skills (2001). *Inclusive school design: Accommodating Pupils with Special Educational Needs and Disabilities in Mainstream schools*, Building Bulletin 94., London: The Stationery Office. ISBN 011271109X.

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 the latest edition of 'Building Bulletin 77: Designing for Special Educational Needs, Special Schools' ¹⁶.

Table 1 Ventilation provisions for special educational needs and special schools

Space	Capability for a minimum air change / hour (ach)	Ventilation mode - 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 <ul style="list-style-type: none"> • 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.

¹⁶ Department for Education and Skills (2005). Designing for Pupils with Special Educational Needs: Special Schools, Building Bulletin 77 (draft). Available at www.teachernet.gov.uk/docbank/index.cfm?id=8693

2.8 Ventilation of other buildings and spaces

Requirement F1 of the Building Regulations may be satisfied by following the appropriate design guidance for the types of spaces/buildings given in Table 2¹⁷ 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 Approved Document F

Activity	Regulations and Guidance
Animal husbandry	The Welfare of Farm Animals (England) Regulations SI 2000: No. 1870 London: The Stationery Office. The Welfare of Farm Animals (England) (Amendment) Regulations SI 2002: No.1646. London: The Stationery Office. The Welfare of Farm Animals (England) (Amendment) Regulations SI 2003: No. 299. London: The Stationery Office. British Standards Institution (2003) BS5502:22 Buildings and Structures for Agriculture CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.24.1 'Animal Husbandry', CIBSE Bookshop www.cibse.org
Atria	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.4 'Atria', CIBSE Bookshop www.cibse.org
Broadcasting Studios	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.5 'Broadcasting Studios (radio and television)', CIBSE Bookshop www.cibse.org
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	Energy Efficiency Best Practice in Housing (2003): Good Practice Guide GPG 192; Designing Energy Efficient Multi-Residential Buildings www.est.org.uk/bestpractice/publications/index.jsp CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.8 'Communal Residential Buildings', CIBSE Bookshop www.cibse.org
Darkrooms (photographic)	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.24.4 'Darkrooms (photographic)', CIBSE Bookshop www.cibse.org
High-rise (non-domestic buildings)	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.12 'High-rise buildings(non domestic)', CIBSE Bookshop www.cibse.org
Horticulture	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.42.6 'Horticulture', CIBSE Bookshop www.cibse.org
Healthcare buildings	NHS Estates (2005) Health Technical Memorandum (HTM) 03; Part 1 – Ventilation in healthcare premises: design and validation NHS Estates (2005) Health Technical Memorandum (HTM) 03; Part 2 – Ventilation in healthcare premises: verification and operational management NHS Activity database NHS Estates Bookshop. ISBN 0113217420, www.tso-nhse.co.uk/Htm.cfm NHS Estates: Health Building Notes - NHS Estates Bookshop www.tso-nhse.co.uk/Htm.cfm CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.13 'Healthcare buildings', CIBSE Bookshop www.cibse.org
Museums, libraries and art galleries	British Standards Institution (2000) BS 5454 Recommendations for the Storage and Exhibition of Archival documents, London: British Standards Institution Bookshop, ISBN 0 580 33151 2 CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.17 'Museums, libraries and art galleries', CIBSE Bookshop www.cibse.org
Plant rooms	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.8 'Plant rooms', CIBSE Bookshop www.cibse.org
Washrooms/ sanitary accommodation	Same as for Offices in Table 2.1a
Transportation buildings and facilities	CIBSE (2001) Guide B2, Ventilation and Air Conditioning, Section 3.23 'Transportation buildings and facilities', CIBSE Bookshop www.cibse.org

¹⁷ Adapted from Table 2.3 of ADF

2.9 Historic school buildings

Designers involved in work on historic school buildings should recognise the need to conserve the building's special characteristics¹⁸. 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. 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 breathe¹⁹. Pressure testing can be used to establish if the fabric of the historic building is leakier than a modern building.

Advice on the factors determining the character of historic buildings is set out in Planning Policy Guidance 15: Planning and the historic environment (PPG15)²⁰.

2.10 Kitchens

Where flueless gas appliances such as cookers are installed, adequate ventilation is required to safeguard against the possibility of incomplete combustion producing carbon monoxide. A mechanical system may be needed to provide this.

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. The HVCA have published DW/171 which is a guide to kitchen ventilation and can be used to help with these issues.²¹

Detailed advice on gas installations can be found in the publication Gas Installations for Educational Establishments UP11²².

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,

¹⁸ British Standards Institution (1998) BS7913 Guide to the Principles of the Conservation of Historic Buildings. London: British Standards Institution Bookshop, ISBN 0 580 29515 X

¹⁹ Society for the Protection of Ancient Buildings (SPAB) (1987) Information Sheet 4, Need for Old Buildings to Breathe London: SPAB Bookshop - www.spab.org.uk/publications.html

²⁰ Office of the Deputy Prime Minister. Planning Policy Guidance 15: Planning and the historic environment. - www.odpm.gov.uk PPG15

²¹ HVCA: Standard for Kitchen Ventilation Systems DW/171.

²² Institute of Gas Engineers and Managers (2004) UP11: Gas Installations for Educational Establishment www.igem.org.uk/Publications_Information.html.

or if the cookers are badly maintained. Guidance on air supplies required to support combustion where cookers are installed is available in BS6173:2001²³.

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 Regulations²⁴, and may need to be interlocked with the gas supply as required by BS 6173²⁵. This type of ventilation may need to be provided at source, by means of Local Exhaust Ventilation, in accordance with COSHH requirements. The HSE guidance note on ventilation of kitchens in catering establishments gives good advice, some of which is applicable to food technology rooms as well as school kitchens²⁶.

2.11 Dining Areas

The smell of food from dining areas can be a nuisance and therefore it is imperative to avoid the transfer of these smells from these areas to the body of the school. This can be a particular problem when atria contain food areas and are linked to large areas of the school.

²³ British Standards Institution (2001) BS6173 Specification for the Installation of gas-fired catering appliances for use in all types of catering establishments (2nd and 3rd family gases), London: British Standards Institution Bookshop, ISBN 0 580 33275 6

²⁴ Health and Safety Executive (1998) L56 Safety in the installation and use of gas systems and appliances - Gas Safety (Installation and Use) Regulations London: HSE Books. ISBN O 7176 1635 5

²⁵ British Standards Institution (2001) BS6173 Specification for the Installation of gas-fired catering appliances for use in all types of catering establishments (2nd and 3rd family gases), London: British Standards Institution Bookshop, ISBN 0 580 33275 6

²⁶ Health and Safety Executive (2000), Catering Information Sheet No 10 - www.hse.gov.uk/pubns/cais10.pdf

3 Indoor air quality and ventilation

People typically spend 90% of their time indoors. Concern over human exposure to the pollutants found indoors, and their potentially adverse effects on the health, productivity, comfort and well-being of occupants, is therefore growing. In busy urban areas, the overall exposure levels inside a building are likely to result from pollutants generated within and outside the building. Achieving good indoor air quality in schools, therefore, depends on minimising the impact of indoor sources, as well as reducing pollutant ingress 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 the building, itself and from cleaning materials and furnishings. The major indoor pollutants and their sources include:

Carbon dioxide (CO₂) – CO₂ is a product of human respiration and combustion. 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;
- the activity levels of occupants;
- the amount of time occupants 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, peaked before lunch time at 12.30pm, and then decreased over the lunch period when the classroom was empty. After lunch, when the classroom was again occupied, CO₂ levels rose to a peak at the end of the school day at 3.30pm²⁷. CO₂ levels from combustion may be particularly high in food preparation areas and in science labs when Bunsen Burners are in use.

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 by 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 odour²⁸. 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 finishes 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;
- perchloroethylene;

27 Kukadia V., Ajiboye P. and White M. (2005). Ventilation and Indoor Air Quality (IAQ) in Schools. BRE Information Paper BRE Bookshop.

28 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.

- methylene chloride;
- toluene; and
- vinyl chloride ²⁹.

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 ³⁰ suggests that concentrations of 0.1 mg/m³ may cause throat and nose irritation.

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 relatively low 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 and bacteria. Normal control measures which apply in schools, such as the COSHH procedures, should limit the risks to an acceptable level. The health implications of smaller airborne particles, such as 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.

Asbestos - Asbestos and asbestos-containing materials (ACMs) are commonly found in schools built or refurbished before 1985. However, some asbestos-containing materials continued to be used up until 1999. If the material is disturbed or becomes damaged, asbestos fibres may be released into the air and could present a risk if inhaled. Some damaged asbestos can be made safe by repairing it and sealing or enclosing it to prevent further damage. Where asbestos cannot be easily repaired and protected, it should be removed by someone who is trained and competent to carry out the task. HSE guidance can help duty holders choose appropriate contractors to carry out this work.

Further information on asbestos in school buildings can be found in the Asbestos Regulations ³¹ and HSE guidance ³².

29 Air Quality Sciences (date) *New Asthma Studies Links VOCs and Allergens to an Increase in Childhood Asthma*

www.aerias.org/uploads/Linking%20IAQ%20and%20Asthma%20in%20Schools.pdf

30 Department of the Environment and the Welsh Office. *The Building Regulations 1991, Approved Document F1: Means of ventilation (1995 edition)*. London, HMSO. Under revision.

31 Statutory Instruments: 1983/1649. *Asbestos Licensing Regulations*
London: The Stationery Office. ISBN: 0 11 037649 8

Statutory Instruments: 1999/2977. *Asbestos (prohibitions) (amendments) (no. 2) Regulations*
London: The Stationery Office. ISBN: 0 11 085450 0

32 Health and Safety Executive (2000), *Asbestos - An Important Message For Schools*
www.hse.gov.uk/asbestos/schools.pdf

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 carcinogen and poses a serious health risk to children, particularly those suffering from asthma.

3.1.1 Minimising indoor pollutants

A number of methods are available for indoor air pollutant control. These are outlined below:

Emission control

Potentially harmful emissions from can be reduced by avoiding sources of pollutants; for example, careful selection of materials can 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 Wales³³. 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 emission³⁴. 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 464³⁵, and information on source control to minimise dust mite allergens is available in BRE Report BR 417³⁶.

Discouraging tobacco smoking

Discouraging tobacco smoking is another means of emission control by which harmful emissions of carbon monoxide and smoke particles can be reduced. It is recommended that smoking be banned in school buildings (Report of the Scientific Committee on Tobacco and Health, 1998)³⁷. However, if the school management chooses 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 ensuring:

- 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 1974³⁸, to protect the

³³ 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 www.danishtechnology.dk/building/13268

³⁴ BS EN 13986: 2002 Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking. London. BSI Bookshop: ISBN 0 580 37500 5

³⁵ BRE Digest 464: VOC Emissions from Building Products Parts 1 and 2; IP 12/03 VOC Emissions from Flooring Adhesives.

³⁶ Raw G. J., Aizlewood C. E. and Hamilton R. M. (2001) Building Regulation, Health and Safety. BRE Report 417. BRE bookshop: www.brebookshop.com/

³⁷ Department of Health (1998) Report of the Scientific Committee on Tobacco and Health
www.archive.official-documents.co.uk/document/doh/tobacco/contents.htm

³⁸ Health and Safety at Work Act (1974)

health, safety and welfare of their employees. HSE booklet *Passive Smoking at Work*³⁹ 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 91/1⁴⁰ 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.

3.2 Related performance-based standards

Approved Document F does not provide performance-based guidance for schools. However, it does recommend performance levels for office-type accommodation.

- The average relative humidity in a room should not exceed 70% for more than two hours in any 12-hour period during the heating season.
- Nitrogen dioxide (NO₂) levels should not exceed 288 µg/m³ (150 ppb) averaged over one hour.⁴¹
- Carbon monoxide should not exceed
 - 100 mg/m³ (90 ppm) – 15-minute averaging time
 - 60 mg/m³ (50 ppm) – 30-minute averaging time
 - 30 mg/m³ (25 ppm) – 1-hour averaging time
 - 10 mg/m³ (10 ppm) – 8-hour averaging time
- Total volatile organic compound (TVOC) levels should not exceed 300 µg/m³ averaged over eight hours.
- Ozone levels should not exceed 100 µg/m³.

In most cases, it would be expected that the pollutant emissions in teaching or learning areas would be similar to those in office-type accommodation. Thus given the higher ventilation rates in schools compared to offices, this guidance should be met. However, there will be some school-specific activities where further consideration is necessary e.g. the use of art materials (e.g. paints) which can result in a high TVOC level.

3.3 Outdoor air pollutants and sources

A wide range of pollutants generated outdoors 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)⁴². These are:

- Carbon monoxide, CO;
- Nitrogen dioxide, NO₂;
- Sulphur dioxide, SO₂;
- Ozone, O₃;
- Particulate matter, PM₁₀;
- Benzene;
- 1,3-Butadiene;
- Lead.

39 Health and Safety Executive (1993), *Passive smoking at work* IND(G)63(L) (Revised), HSE Books - www.hsebooks.com/Books

40 HSE (2000) Local Authority Circular LAC 91/1 - www.hse.gov.uk/lau/lacs/91-1.htm

41 Department of Health, Committee on the Medical Effects of Air Pollutants (2004) *Guidance on the Effects of Health of Indoor Air Pollutants* www.advisorybodies.doh.gov.uk/comeap/PDFS/guidanceindoorairqualitydec04.pdf

42 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 (2000). *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*. London: The Stationery Office ISBN 0 101454 82 1.

Although nitrogen oxide, NO, is not included in the NAQS, it is a normal constituent of combustion discharges, and in many cases is the largest polluting emitter. This is especially the case for gas-fired plant. NO is readily oxidised to NO₂ so both these gases need consideration.

Sources of outdoor pollutants include:

- 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;
- air traffic can result in emissions and noise, particularly near large airports such as London Heathrow
- combined heat and power plant (CHP);
- 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 and fume cupboards or other local exhaust ventilation discharges;
- construction and demolition sites. These are sources of particles and vaporous discharges;
- agricultural processes. In intensively farmed areas, bacteria, pollen, fungi and odours 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.

3.3.1 Minimising 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 timescales. 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)⁴³.

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 Areas⁴⁴ where, by definition, pollution levels of at least one pollutant have exceeded the Air Quality Standards⁴⁵. The siting of exhausts and fume cupboard discharge stacks is also important – this is discussed below.

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

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

44 For Air Quality Management Areas see: www.airquality.co.uk/archive/laqm/laqm.php

45 Air Quality Management (2002). Air Quality Strategy Wallchart – Summary of Proposed Objectives in the Latest Consultation, November 2002. Gee Publishing.

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.

Control of ventilation intakes

The concentration of pollutants from sources such as urban road traffic, fluctuate with the time of day. In such cases, reducing the flow of external air or closing ventilation intakes for up to an hour during periods of high external pollutant concentrations may be an option. Automated control using time controls and a sensor for the relevant pollutant will probably be required. Closing air inlets during rush hour may also be desirable to prevent the ingress of noise as well as traffic fumes.

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 and food smells through the atria can make this difficult. 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 3 m is desirable in a naturally ventilated classroom or other teaching space. This is even more desirable in science labs, prep rooms and workshops, where activities may result in higher pollutant emission. Further details of this principle with examples may be found in: Liddament, M.W (2000) *Indoor Air Quality Handbook, Chapter 13: Ventilation Strategies*, McGraw-Hill.

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
<p>Local static sources:</p> <ul style="list-style-type: none"> • Parking areas; • Welding areas; • Loading bays; • Adjacent building exhausts; • Stack discharges. 	<p>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 TM21⁴⁶.</p>
<p>Urban traffic</p>	<p>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 be sought.</p> <p>For buildings located one or two streets away, the placement of intakes is less critical.</p>
<p>Building features/layout:</p> <p>Courtyards:</p> <p>Street canyons:</p>	<p>Intakes should not be located in these spaces where there are air-pollutant discharges. This includes emission discharges from building-ventilation-system exhausts.</p> <p>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.</p>
<p>Multiple sources</p>	<p>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.</p>
<p>Weather factors</p>	<p>In areas where predominant wind comes from opposing directions (e.g. a valley location), the air intakes and outlets should point in opposite directions.</p> <p>In complex urban layouts, complex wind flows are likely to occur. In these cases, expert advice may be required.</p>

46 Chartered Institute of Building Services Engineers (1999). CIBSE Technical Memorandum TM21 on Minimising Pollution at Air Intakes. CIBSE Bookshop: ISBN 0 900953 91 8.

Filtration

Filtration provides a means of cleaning the intake air. It is standard practice to fit filters to mechanical ventilation systems. Mechanical systems can, because of this, be perceived as providing cleaner air to the space. However, it must be noted that filtration systems are only effective at dealing with the pollutants they are designed for. Mechanical ventilation system air-intake filters are primarily used for particle removal. Activated carbon filters are required if it is necessary to remove gaseous pollutants. As these are exceptionally demanding and costly it is preferable to avoid the need for removal of gaseous pollutants from outside air by effective positioning of intakes.

Building 'airtightness'

An airtight building envelope will prevent the uncontrolled ingress of contaminated outdoor air. The implications of 'airtightness' for building energy use, rather than ingress of air, are addressed in Approved Document L of the Building Regulations (2006).

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 ($\text{m}^3\text{h}^{-1}\text{m}^{-2}$) 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 $10 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$. All buildings over 1000 m^2 gross floor area must be tested to meet this criterion. Full details on achieving and verifying performance are given in the ATTMA publication 'Air Permeability Measurement'⁴⁷.

Construction and retrofit, to at least the current Regulations, should be regarded as essential to prevent the uncontrolled ingress of pollutants.

⁴⁷ *Air Permeability Measurement*, Air tightness Testing and Measurement Association (ATTMA);

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. However, classroom occupants are typically 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.

Modern schools will generally be much more air tight than previously and it is critical that users have control of the ventilation and understand how to use it: guidance should be provided in the building log-book and handover information (see section 7).

The current trend towards maximising use of the available floor area through design of deep plan spaces and the increased use of ICT has led to concerns about overheating in classrooms. This has renewed interest in natural and mechanical ventilation systems that will perform better than the simple window-opening approach of previous school designs, and incorporate passive cooling.

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 also requires 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; ClassVent⁴⁸ is a simple tool that will greatly assist in the design process. To increase occupant satisfaction, the ventilation system must be controllable, and integrated in such a way that draughts are avoided.

4.1.2 Hybrid ventilation

A potentially more environmentally and financially sound solution than adopting a full mechanical ventilation system 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 –

48 DfES (2006) ClassVent - www.teachernet.gov.uk/iaq

without ductwork for air transport – but provision is made to assist the airflow through the space when natural driving forces are inadequate. To ensure that the airflow is not restricted, care must be taken with partitioning and the use of down-stand beams that may interrupt the airflow and its contact with exposed soffits.

Hybrid ventilation can therefore lower the capital costs of the ventilation system by reducing ductwork and the space required for plant rooms. It can also lessen the running costs for cleaning and maintenance compared to a full mechanical ventilation system.

In this form hybrid ventilation can also be better suited to using the thermal mass of the building fabric than a full mechanical system where suspended ceilings used to hide ductwork, may reduce the potential for contact of the air with the thermal mass. Controlling the hybrid system to provide night cooling may also be easier than a natural ventilation only solution because a single extract point can be provided for a large area of the school and the increased pressure drops provided by the fan.

The concern that changing practice in the use of schools or changes in climate may require the adoption of mechanical ventilation, is addressed in CIBSE's Applications Manual 13⁴⁹. This 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 ventilation

Mechanical systems are expensive but may offer an advantage in energy terms as they do allow the option of providing heat recovery. However, in schools this is less attractive than may be thought because for most of the occupied period the internal gains are high and will provide most of the heating load. Heat recovery is then less valuable. Therefore, although heat recovery improves the energy efficiency of mechanical ventilation systems it will rarely be cost effective in a school.

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.

Both mechanical and hybrid ventilation systems lend themselves to control by a BMS or other similar system. Hence, mechanical ventilation may be controlled directly by level of CO₂ measured in the space or in response to sensing of the occupancy of the space. If associated variable speed control fans are used then the ventilation rate supplied and the fan energy used can more closely match the demand profile.

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 1.1a Approved Document F). Provision should be made to protect the fresh-air supplies from contaminants hazardous to health.

49 CIBSE (2000). Mixed Mode Ventilation, Applications Manual AM13, CIBSE Bookshop: ISBN 1 903287 01 4

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 ⁵⁰.

Table 4 Ventilation rates for local extract ⁵¹

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: <ul style="list-style-type: none"> • 6 ach ⁵² or; • 15 l/s per shower/bath or; • 6 l/s per WC.
Food and beverage preparation areas (not commercial kitchens); including food-technology areas.	Intermittent air-extract rate of: <ul style="list-style-type: none"> • 15 l/s with microwave and beverages only; • 30 l/s adjacent to the hob with cooker(s); • 60 l/s elsewhere with cooker(s). <p>All to operate while food and beverages preparation is in progress.</p>
Specialist rooms (e.g. commercial kitchens, fitness rooms)	See Table 2.3 of Approved Document F

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 3 l/s per person – not the capability of 8 l/s per person. In

⁵⁰ HSE (2000) Local Authority Circular 90/2 - www.hse.gov.uk/lau/lacs/90-2.htm

⁵¹ Adapted from Table 2.1a of ADF

⁵² This is specified in the School Premises Regulations - Requirement 21(3)

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 do allow the ingress of 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 BB93⁵³ 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 level⁵⁴ dominated by road traffic, facades with typical manually controlled 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.

Automatically controlled windows, and other vents that allow close control of the open area, can provide considerably better sound attenuation of up to 20 dBA - 30 dBA. If classrooms are located on the noisy facades, normal manually opening windows might not be possible, but automatically or other closely controlled windows, roof-mounted ventilators or sound-attenuated openings might be an option⁵⁵.

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 noise levels from these actuators are kept well below the indoor ambient noise levels given in Table 1.1 of Building Bulletin 93.

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 neighbouring activities. However, specialist acoustic advice is needed where levels higher than those proposed in Section 1.5 are proposed. Section 1.2.1 of BB93 permits the use of Alternative Performance Standards. These provide scope for designers to increase the indoor ambient noise levels on a selective basis where, for environmental, educational or health and safety reasons, it would be preferable to allow a higher indoor ambient noise level.

53 Department for Education and Skills (date). Acoustic Design of Schools – a design guide, Building Bulletin 93. London: The Stationery Office. ISBN 0 11 271105 7 - www.teachernet.gov.uk/acoustics

54 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.

55 Sound Measurements and Natural Ventilation in Schools: Alice Andersen, Carl Hopkins. International Journal of Ventilation: Volume 4 No.1 June 2005 Edition

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 airflow and noise attenuation are available to control noise ingress from outside and sound transmission between spaces. Reference to Building Bulletin 93 and suitable case studies is essential for a full understanding of the issues⁵⁶.

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.

Research⁵⁶ into the sound attenuation and airflow characteristics of different configurations of a prototype ventilator, intended for cross-flow ventilation in schools, shows 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 naturally driven cross ventilation using the stack effect of an atrium⁵⁷.

4.3.3 Mechanical ventilation noise

Mechanical ventilation systems are not silent, and the standards in BB93 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. In addition, 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 early in the design process as it may limit some design solutions. It should also be remembered that mechanical systems should be capable of providing 8 l/s per person at all times and the indoor ambient noise levels given in BB93 Table 1.1 should not be exceeded when the mechanical ventilation system is operating at its maximum specified airflow rates.

4.4 Fire precautions

Note that Approved Document B⁵⁸ 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.

56 BRE Client Report (2004): A prototype ventilator for cross ventilation in schools: Sound insulation and airflow measurements. Client report number 220497 - www.bre.co.uk/filelibrary/DFES_cross_ventilator_complete_report.pdf

57 M White, G McCann, R Stephen, M Chandler (1999) Ventilators: ventilation and acoustic effectiveness, IP 4/99. BRE Bookshop: ISBN 1860812643

58 ODPM Building Regulations (2002): Approved Documents B, Fire safety 2000 (consolidated with 2000 amendments and 2002 amendments). London: The Stationery Office.

Fire precautions may be required to ensure that compartmentalisation 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.⁵⁹

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 J⁶⁰ 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 including:

- a. access to replace filters;
- b. access points for cleaning ductwork;
- c. access to replace, maintain and repair fans, heat exchanger and other HVAC plant.

Adequate space should be provided in plant rooms for the maintenance of the plant. Approved Document F recommends that where **no special provision** is required, 600mm space should be provided where access is required between plant, and 1100mm where space for routine cleaning is required (see Diagram 4 in Approved Document F). These are guidelines for the minimum space needed and additional space may be needed for opening of access doors, withdrawal of filters, etc.

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*.⁶¹

59 Department for Education and Skills (2000). Designing Against The Risk Of Fire In Schools Building Bulletin 100
London: The Stationery Office. ISBN 0 11 271040 9 - www.teachernet.gov.uk/_doc/971/SBfire_safety_guide%5B1%5D.pdf

60 ODPM Building Regulations (2001): Approved Documents J, Combustion appliances and fuel storage systems (2002 edition).
London: The Stationery Office.

61 Ministry of Defence (1996) Space Requirements for Plant Access and Operation, Design and Maintenance Guide 08
London. The Stationery Office ISBN 0 11 772785 7

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 specified in section 1.4 of this Building Bulletin, the requirement for ventilation of teaching and learning spaces is based on the capability to provide each person with 8 l/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. To provide adequate cooling during the daytime in summer this ventilation rate will most likely need to be greater than 8l/s per person. Similarly, for night-time cooling of the thermal mass of the building higher air flow rates may be required.

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.

The Department for Education and Skills has provided the ClassVent⁶² calculator to be used with Building Bulletin 101 that enables a designer to rapidly calculate areas for airflows into and out of a classroom. Designs using the ClassVent calculator could be considered as satisfying the guidance given in Section 1.4 of this Building Bulletin when used with the design conditions specified in Section 5.4.2. Other design tools can also be used, but calculations for these designs would need to be submitted for building control approval.

In addition to ClassVent, a complementary tool has also been provided, ClassCool, which provides a simplified method of assessing the extent of classroom overheating. This is described in section 8.1. The common link between these tools is the ventilation rate. Typically, ventilation rates required for achieving good indoor air quality are lower than those to limit the risk of overheating. Therefore, when using these tools an element of 'iteration' may be required to achieve a design that satisfies both heating season and non-heating season requirements.

The ClassVent tool is available from the Department's website, together with 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; the stack effect, and wind pressure (or the 'wind effect').

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

The stack effect does not actually rely on a physical 'stack' or chimney. In a classroom that is warmer than outside and has two separate openings in a wall, a pressure difference will exist across the wall and cause air to flow into the lower opening and out of the upper opening.

62 DfES (2006) ClassVent - www.teachernet.gov.uk

As the temperature inside and outside the building becomes more equal (in summer for example) the pressure drop across the openings, and hence the stack effect, decreases, reducing the ventilation rate. To counter this effect the total openable area of the facade must be increased.

Wind pressure also influences the ventilation of a building by creating variations in pressure around the outside of the building. Variations in pressure are highly dependent on the building form and the wind speed and direction. Typically, an increase in pressure is experienced on the façade facing the wind and a negative pressure is experienced on the other façades. 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 simple, regular building forms and for particular wind patterns. For more complex building designs, wind pressure coefficients may need to be determined by 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 airflow. Even though the wind speed is typically greater than 3 metres per second (m/s) for most places in the UK, and will often assist the stack effect, it is advisable to consider the performance for a still, or relatively calm, day as this is the most challenging condition. At the early design stages it is advised that simple strategies relying on the more predictable stack effect are adopted, particularly if detailed information about wind-pressure coefficients and wind speed and direction is not available.

Simple natural ventilation calculations are open to error as they are approximations based on the bulk properties of the air. However, even detailed Computational Fluid Dynamics (CFD) models used by a highly skilled modeller will not necessarily improve on the accuracy of simple empirical equations. Therefore, the simple ClassVent model is likely to be a good starting point for proving the adequacy of natural ventilation designs.

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 tool allows the user to choose one of the following ventilation strategies:

- single-sided ventilation with a single opening;
- 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;
- split duct roof-mounted ventilation.

The range of ventilation strategies available in the ClassVent tool are illustrated in sections 5.3.1 to 5.3.4. The discussion assumes the internal temperature is higher than the external temperature. The situation is similar if the opposite is true, except the flow directions are reversed.

5.3.1 Single sided ventilation



Figure 1(a) Single sided ventilation: a single openable window or vent

The strategy shown in Figure 1(a) uses a single ventilation opening, normally the openable part of the window or a single grille. Air flows in from the lower part of the opening and out from the upper part. In ClassVent, the user specifies the height of the opening and distance from the floor to the midpoint of the opening. The tool provides the area of the opening. This is sensitive to the height of the window: a tall and thin window will produce more air flow than a short and wide one of the same area. It is advised to investigate this option to see the basic area requirement before looking at other strategies. The area required will increase using the summer settings because the temperature differential between inside and outside is smaller, hence there is less ventilation driving force.

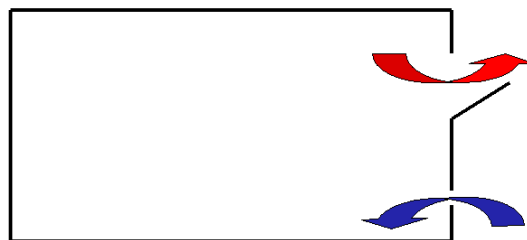


Figure 1(b) Single side ventilation: a single low level vent and one openable window

The strategy in Figure 1(b) depicts single side ventilation with two ventilation openings at separate levels. This can be a low or high level ventilation grille with a window: the upper one can be sized by the user. Air flows in from the bottom opening and out via the top one. The user specifies the distance from the floor to the midpoint of the openings, and optionally also the area of the top opening (whether it is an openable window or a vent). The work sheet sizes the area of the bottom opening as function of the area of top one. The user can alter the area of the top opening until the calculation has produced a suitable vent area.

5.3.2 Cross flow ventilation

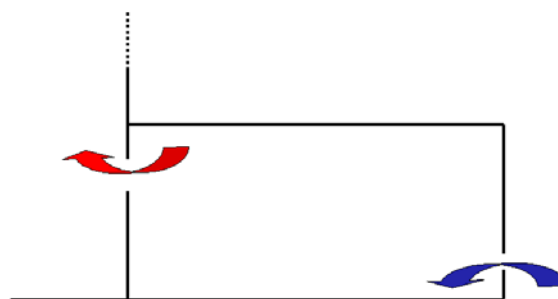


Figure 1(c) Cross flow ventilation: one opening on the front façade and one on the rear wall

Figure 1(c) shows the cross flow ventilation strategy. The work sheet for this in ClassVent allows for two openings on opposite walls. The user must specify the height from floor to mid-point of the openings and the area of the exhaust vent if desired. The work sheet presents the area of the individual openings, or, if wind is present, the user can input the outlet area to produce the inlet area. Cross Flow calculations take account of wind speed, but the sheet will also allow a 'no wind' case. The user should try to maintain a reasonable height differential between inlet and outlet, to ensure that there is enough driving force for the strategy to be effective in the "no wind" case. If the openings are of equal height from the floor, the depths of the windows are also required.

Cross Flow calculation can also take account of wind speed and floor height and will produce the results for the top floor. The user can define the building as a 1 storey building to see results for the ground floor classroom, classroom, then define it as a 2 storey and read the first floor results, etc.

When considering this method of cross flow ventilation care must be taken not to allow noise transmission and suitable acoustic transfer grills will be required. See section 4.3.2.

5.3.3 Stack ventilation

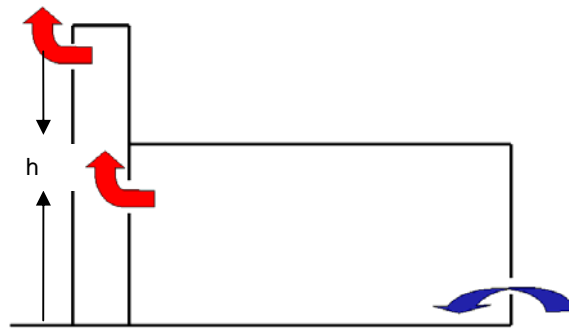


Figure 1(d) Stack ventilation: one front façade opening, one transfer vent on the back wall into a stack

Stack ventilation is shown in Figure 1(d), in which two ventilation openings, a low level grille and high level one, typically placed above the door. Air flows in from the front and out via the corridor or any adjacent space into a stack. This calculation requires an input for the floor to floor height and the number of floors. The user specifies the height from floor to mid-height of the façade opening, as well as the height (h) of the stack. The user should also input areas for the stack outlet and the back wall vent which feeds into the stack. The calculation gives the area required for the inlet vents on the façade. This calculation also allows for a wind input. Select 'no wind' to produce the worst case scenario.

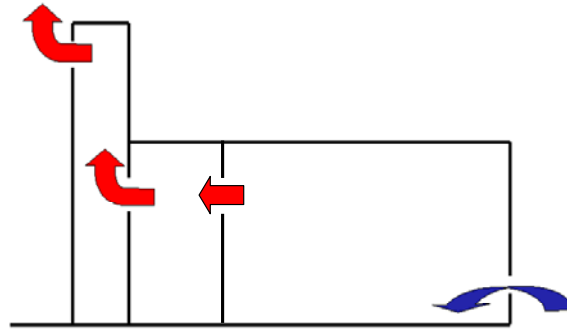


Figure 1(e) Stack Ventilation: one front façade opening, transfer vent into corridor, transfer vent into stack

Figure 1(e) indicates stack ventilation via a corridor. Two ventilation openings, a low level grille and high level one, which is typically placed above the door. Air flows in from the front and out via the corridor or any adjacent space into a stack. This calculation requires an input for the floor to floor height and the number of floors. The user specifies the height from floor to mid-height the façade opening, as well as the height of the stack. The user should also input areas for the stack outlet, the back wall vent which feeds into the corridor, and the area of the next opening from the corridor to the stack. The calculation gives the areas of the inlet opening on the façade. This calculation also allows for a wind input. 'No wind' should be selected to produce a worst case scenario.

5.3.4 Split-duct roof mounted ventilation

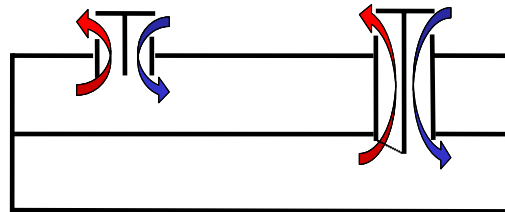


Figure 1(f) Split-duct roof mounted ventilation

Roof-mounted split ventilators, as shown in Figure 1(f), 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. The single roof terminal is usually divided internally to obtain 4 separate quadrants which flow independently. Examples include "Windcatcher", "Windvent" and "Airscoop"⁶³ Outdoor air flows in through some of the quadrant chambers and indoor air flow out from others. The terminal is self adjusting choosing naturally the flow direction in each quadrant, depending on the wind direction. The user specifies the height of the inlet/outlet grille from its midpoint to the ground, as well as the distance from the midpoint of external grille to the roof level and the vertical distance from the ground level to the midpoint of the internal grille. This allows the user to specify long ducts for classes situated at lower level. Two results are provided, one for the windless condition which relies purely on internal to external temperature differential, and one for when wind is present, which ignores buoyancy effect due to temperature.

63 BSRIA (2005) Wind-Driven Natural Ventilation Systems, BG2/2005, BSRIA Bookshop: ISBN: 0860226476 - www.bsria.co.uk/bookshop/pages

5.4 Design stages

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

- concept design;
- scheme design;
- detailed design.

This section discusses the information needed for the first two 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 the Department for Education and Skills⁶⁴.

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 at the earliest design stage. Table 5 highlights key design features which can either make natural ventilation successful or more difficult.

Table 5 Key design features affecting success of natural ventilation

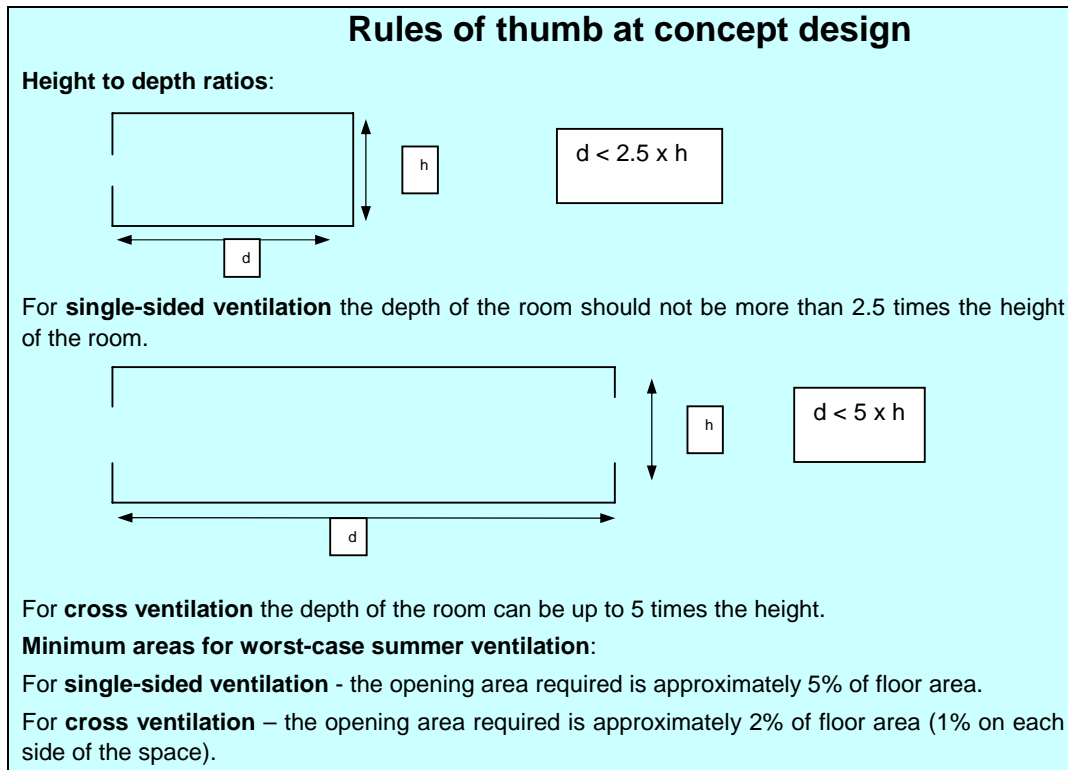
Success factors	Problem issues
Narrow plan	Deep plan
Two-sided façade	Single-sided narrow plan
High ceilings	Low ceiling heights
Thermally heavyweight construction	Thermally lightweight construction
Controlled internal gains	High incidental heat gains – particularly solar and from ICT equipment
Low external noise levels and controlled indoor ambient noise levels	High external noise levels and uncontrolled indoor ambient noise levels

Table 5 shows factors with 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 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 provide a separate ventilation opening to meet the winter ventilation requirement. Using large windows might also lead to lower airtightness, unless they are well sealed when closed, and may lead to draughts and infiltration energy loss.

Figure 2 summarises simple rules of thumb for selecting a ventilation strategy

⁶⁴ DfES (2006) ClassVent - www.teachernet.gov.uk



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 similar 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.

Figure 2 Rules of thumb for selecting a ventilation strategy

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 ClassVent calculator is a spreadsheet implementation of the ventilation design principles described in CIBSE AM10 and other sources of information on natural ventilation air flows. The tool provides a quick method of establishing the areas required to provide the necessary air flows for a range of design solutions. It assists at the scheme design stage by providing guidance on location and size of openings that must be accommodated by the architecture of the building. An example of how to use ClassVent is given in Section 6.

5.4.3 Detailed design stage

The detailed design stage will take forward the results of the ClassVent calculations and translate these into actual component areas and locations together with the controls needed for their operation. It is often desirable to use more detailed dynamic simulation tools at this stage of the design: particularly if ventilation is to be used for night cooling.

6 ClassVent calculator

The ClassVent calculator 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 the CIBSE Applications Manual 10⁶⁵. The underlying calculations are based on the design methods contained in AM10 and the embedded equations for determining the flows are derived from BS 5925⁶⁶ and CIBSE Guide A⁶⁷.

Note that Approved Document F and the ClassVent calculator use 'equivalent area' instead of 'free area' for the sizing of ventilators. Equivalent area is a better measure of the airflow 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 airflow 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 airflow performance. A new European Standard, BS EN13141-1:2004⁶⁸, includes a method of measuring the equivalent area of background ventilator openings.

6.1 Typical Design Conditions

The ClassVent tool is tailored to a school classroom. Figure 3 shows the ClassVent user interface. 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 airflow. The user can then select the design conditions by specifying the temperature profile from one of three defaults:

- winter temperature profile;
- summer temperature profile;
- mid-season temperature profile.

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. Table 6, below indicates suitable design conditions on which to base the ClassVent calculations.

Table 6 Typical design conditions for use in ClassVent

Season	Internal temperature	External temperature	Wind speed*
Summer	27	24	1.5
Mid-season	20	11	1.5
Winter	20	5	1.5

*Designers should choose a local wind speed of around 1.5 m/s which provides a fairly conservative estimate as very calm days are uncommon in the UK. However, it is also advisable to consider a calm day when the wind speed is zero.

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. It is

65 CIBSE (2005). Natural Ventilation in Non Domestic Buildings (2005 revision), Applications Manual AM10. CIBSE Bookshop: ISBN 1 903287 56 1

66 British Standards Institution (1991) BS5925 Code of Practice for Ventilation Principles and Designing for Natural Ventilation AMD8930, London: British Standards Institution Bookshop, ISBN 0 580 19285 7

67 CIBSE Guide A 1999

68 British Standards Institution (2004) BS EN131411:2004 Ventilation for buildings – Performance testing of components/products for residential ventilation – Part 1: Externally and internally mounted air transfer devices.

important that the designer investigates the range of ventilation requirements between 3l/s per person and 8l/s per person over the various seasons as this significantly affects the areas required. Consequently, design decisions are required as to how to provide suitable areas and locations for winter and summer conditions; and the means by which the occupant controls the areas provided. Naturally, the designer should also consider the results of the overheating analysis given by ClassCool if this indicates that higher air flow rates are required for either daytime or night time cooling.

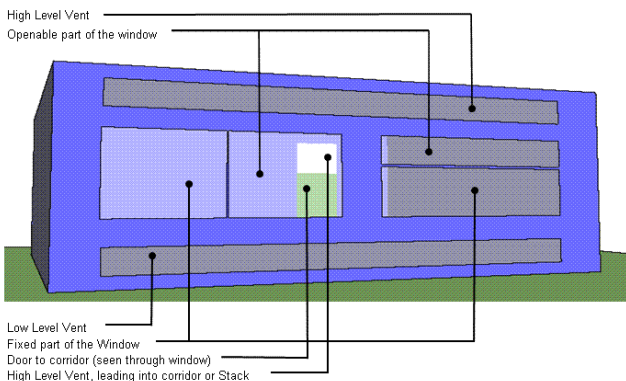
The area and location of openings can be assessed and suitable ventilators provided to meet these requirements for each of the design options. It is important to note, at this stage, that ventilation openings do not have to be windows. Whilst windows were traditionally used to provide ventilation they 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 will be difficult to control to provide the typical levels of ventilation required during the day and in a manner that would not cause draughts. It is likely that the design solution will be a combination of high-level and low-level vents with a central openable window for additional ventilation, for instance, to help control over-heating. Low level vents should not expose the occupants to draughts and so some form of tempering of incoming air in winter will be needed – for example, placing the inlet behind a radiator.

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. Section 6 has more information about types of windows and other ventilation openings.

Classvent - This tool produces the "equivalent" area of ventilation openings required for the supply of a specific volume flow per person

Legend of typical ventilation elements



ClassRoom Geometry	
Width - m	7.70
Depth - m	7.00
Ceiling height (or highest level for opening) - m	3.00
Slab height - m	3.33
Number of Floors	1

ClassRoom Occupancy	
Number of Pupils	30
Teacher (1 or 2?)	2

Design and Enviromental Variables		
Temperature Profile - default season or user input	Winter	
Default temperatures	Outside	Inside
Winter	5	20
MidSeason	11	20
Summer	24	27
Other - User defined temperatures	16	24

Required Volume flow	8 l/sec/per
Equivalent to (m ³ /sec)	0.26
Equivalent to (ach)	5.7

Go to any strategy by clicking			
Single Vent	Here	Stack (room + stack)	Here
Vent & Window	Here	Stack (rooms+corridor+stack)	Here
CrossFlow	Here	Roof Terminal	Here

This spreadsheet is a simple tool to predict the area of the openings needed to provide external air under specified conditions. The recommended ventilation values are: 3, 5 or 8 litres/second/person. The User should enter the geometry and occupancy for the room and then progress through the various design scenarios as indicated on the tabs below. Six possible combinations are given that include variations of Single Sided, Crossflow, Stack ventilation and roof mounted split-duct terminal. The "Single Vent" is either a single opening like a window or a vent; the "Vent Window" has two identical vents at different heights, but also allows the user to change the area of the top vent/window (which will then produce a different area for the bottom vent/window). The "CrossFlow" case looks at displacement ventilation with the windows/vents on two opposite walls; the "Stack(single)" and "Stack(multiple)" cases look a stack ventilation with either a room flowing directly into a stack, or a number of rooms flowing into a corridor which is connected to the stack. The "Roof Terminal" case looks at split-duct devices like the "Windcatcher" (Monodraught), "Airscoop" (Passivent) or "Windvent" (Midtherm). Most cases allow a multi-storeys layout and the presence of wind. The temperatures recommended as the default conditions for each period of the year are as shown in the table above. The tool provides the area required to provide the ventilation rates requested by the user and it also provides the pressure at the inlets/outlet for the windless condition. **Note: the areas predicted are equivalent areas - i.e. they will pass the same volume of air as a square edged orifice of the same area.** The "hole in the wall" to install an actual ventilator that provides this equivalent area will be greater than these calculations imply. See the "Equivalent Area" page for more informations.

Figure 3 Image showing user ClassVent user-friendly interface

7 Design Options

Once the ventilation strategy has been selected, and the size and location of the vents determined, the type of vent opening and the means of control need to be chosen. This chapter gives some guidance as to typical options that are available but others may be devised for specific applications.

7.1 Vents

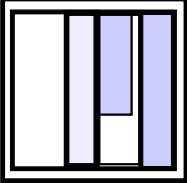
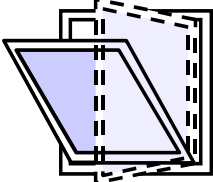
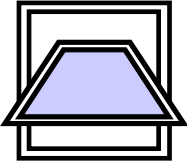
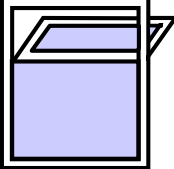
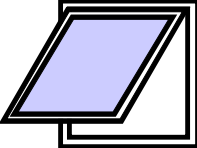
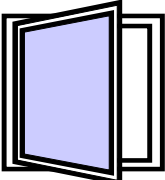
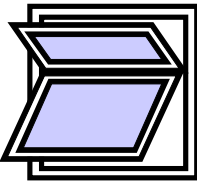
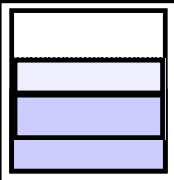
For natural ventilation systems vents typically fall into the following types; windows (including roof lights), dampers, louvres, roof ventilators and trickle ventilators. All types of vent openings should be assessed against the criteria outlined below:

Ventilation capacity	will the device provide the required airflow, given the pressure difference available?	This will depend on the way the vent opens and also for windows on the enclosing head, sill and jamb.
Controllability	is the opening easily controlled by the occupant?	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 from windows can be minimised by restricting the length or throw of stays or actuator arms.
Sealing	will it be airtight when closed and is this durable?	The life expectancy of seals should be comparable to the life of the window
Vent actuators	can the actuators be combined with automatic systems and are they quiet in operation?	This should be considered with care to maximise potential performance.
Acoustic attenuation	do the openings provide sufficient sound insulation when in the open and closed positions	

7.1.1 Windows

Windows (together with doors and roof lights) 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 ensure effective natural ventilation; different window types have varying ventilation characteristics, acoustic properties and weather protection. Their performance can be compromised by blinds, shutters or louvers used for solar control or blackout purposes and this needs to be taken into account when selecting the window type. Some of these features are described in Table 7.

Table 7 Characteristics of different window designs

Window type	Airflow	Ventilation control	Weather protection	Night ventilation	Comments	
Horizontal sliding sash	Very good	Medium	Medium	Medium	No obstruction of internal blinds or external paths – can be draughty	
Tilt and turn	Good	Good	Good	Medium	Control is complex can reflect noise into classroom and turn function can be difficult with blinds – good at providing draught free winter ventilation	
Centre pivot	Very good	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. Can provide good control of external noise from ground level	
Top-hung outward opening	Good – but less so if restricted opening	Medium	Very good	Good	Can reflect noise from beow 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. Can pose a hazard if opening over a path or playground	
Upper fanlight and outward opening casement	Good	Very good	Very good	Very good	Good all round performance. Can pose a hazard if opening over a path or playground – possible rain ingress	
Vertical double sash	Very good	Good	Medium	Medium	No obstruction of internal blinds or external paths.	

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 usually 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 passage for the air. (See Building Bulletin 93 page 30⁶⁹).

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 windows are 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 situated at view window height.

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. Top-hung and 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 as a planted border can prevent this.

It should be noted that window sills, reveals, internal and external blinds have a major impact on the equivalent area which is finally achieved. Further guidance on calculating the equivalent area can be found in BS 5925: 1991 Code of practice for ventilation principles and designing for natural ventilation⁷⁰. The comments in section 4.4 regarding fire safety should also be noted.

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.

7.1.2 Dampers

Dampers are commonly used effectively in mechanical systems. In natural ventilation systems, 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.

7.1.3 Louvres

Louvres usually have glazed or aluminium blades. Fitting security bars inside louvres enhances their potential for night cooling. Some glass louvres have good seals, but these should be carefully

⁶⁹ Department for Education and Skills (date). Acoustic Design of Schools – a design guide, Building Bulletin 93. London: The Stationery Office. ISBN 0 11 271105 7 - www.teachernet.gov.uk

⁷⁰ British Standards Institution (1991) BS5925 Code of Practice for Ventilation Principles and Designing for Natural Ventilation AMD8930 London: British Standards Institution Bookshop, ISBN 0 580 19285 7

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 the space can avoid the potential clash with internal blinds. Louvres are available that can be controlled automatically and linked to a building-management system.

7.1.4 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 and is exhausted from the building on the down-wind side of the ventilator. Roof ventilators 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 have 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 days⁷¹ 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 in 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 manufacturers with performance curves for all of their products.

7.1.5 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 typical in classrooms, 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 certain conditions, they do not perform well. In 'mid-year' conditions, a single-sided ventilation strategy, with four trickle vents each with free area of 4000 mm² i.e. 16,000 mm² of free area provided by inlets and outlets of 8,000 mm² vertically separated by 2 m, will only provide about one twentieth of the air required and will definitely not provide adequate ventilation to ensure satisfactory indoor air quality for the occupants. Trickle vents have a limited role in the provision of ventilation in schools.

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.

⁷¹ See, for example, Gage S. A., Graham, J. M. R. "Static split duct roof ventilators", *Building Research & Information*, Vol 28, No. 4, July 2000, pp 234-244
Kirk S., Kolokotroni M., (2004) "Windcatchers in Modern UK Buildings: Experimental Study", *International Journal of Ventilation*, Vol 3, Issue 1, June 2004, pp 67-78

7.1.6 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.

7.2 Control of ventilation

7.2.1 Introduction

It is important that ventilation is controllable to maintain reasonable indoor air quality, and to avoid draughts and 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.

7.2.2 Occupant control

Occupants need to be able to control the ventilation system, regardless of the system 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.* Paragraph 3.2 of Approved Document N⁷² (1998 edition):

- *Where controls can be reached without leaning over an obstruction they should not be more than 1.9 m above the floor or other permanent stable surface provided to give access. Small recesses, such as window reveals, should be ignored.*
- *Where there is an obstruction the control should be lower, e.g. not more than 1.7 m where there is a 600 mm deep obstruction (including any recess) not more than 900 mm high.*
- *Where controls cannot be positioned within safe reach from a permanent stable surface, a safe means of remote operation, such as a manual or electrical system, should be provided.*

Simple and intuitive controls may therefore provide the most reliable and robust solution. 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.

It would be beneficial to provide the occupants with some visual display of the conditions in the room. For example, this may be a display of the CO₂ level either directly or by means of a 'traffic light' system by which the occupants could judge the need for increased ventilation.

72 ODPM Building Regulations (2000): Approved Documents N, Glazing – safety in relation to impact, opening and cleaning, 1998 Edition, amended 2000, London: The Stationery Office.

7.2.3 Automatic control

In today's increasingly sophisticated school designs it is reasonable to consider the use of an automatic natural ventilation system together with CO₂ sensing. Given the inherent benefits of natural ventilation, and that when well designed and properly controlled, its performance can approach the equivalent consistency 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 CO₂ sensing, and possibly temperature control to provide night-cooling control, and to limit excessive heat loss in winter.

The use of sophisticated building management systems (BMS) is becoming widespread as the technology becomes less costly. Using a BMS, together with sensors, such as local passive infrared detectors or CO₂ concentration sensors located within the building, can maintain precise control over the ventilation of the school. The control can also be linked to 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 CO₂ levels throughout the day.

7.2.4 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;
- linear sleeved cable or rod actuators: often visually intrusive and cumbersome, these are used in some Victorian schools.

It is important that any window and ventilator operating mechanisms are virtually silent. They should act as infrequently as possible, 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 incrementally modulated actuators rather than fully open fully closed modulation. It is best if these can be over-ridden by the teacher to provide purge ventilation when required.

7.3 Example of design study

The following example demonstrates the use of ClassVent to calculate the ventilation areas required to provide a given ventilation rate. Note that the areas given are equivalent areas and the physical dimensions of the actual vent or window will depend on its particular characteristics and may need to be calculated separately to achieve this equivalent area. The example also indicates how this affects the design option.

The following parameters are assumed for this example:

- a standard classroom with a floor area of 54 m² with 30 pupils and 2 adult occupants
- the classroom meets the simple rule of thumb criterion (see section 5.4.1) for single-sided ventilation
- a ventilation rate of 8 l/s per person needs to be achieved for indoor air quality - note that a higher rate may be needed for controlling overheating (see Section 8)
- the periods of interest are winter, mid-season and summer and in this case, the conditions suggested in Table 8 have been chosen.

- wind conditions of zero wind (calm) 1.5 and 3.0m/s local wind speed

Table 8 Assumed design conditions for example case study

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.

7.3.1 Steady state calculation of area requirements using ClassVent

Entering the basic input data into the ClassVent calculator allows assessment of the area requirements for various design strategies. The results for six design strategies are shown in Table 9 below. Note that the results are based on zero wind speed.

Table 9 ClassVent case study results for six design strategies at zero wind speed

Design condition	Winter		Mid season		Summer	
	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 at 1.85m height	1.3		1.7		3.0	
Single sided - equal area low and high level openings separation of 0.6 m	0.8	0.8	1.0	1.0	1.7	1.7
Cross flow - equal area openings same height of 1m - no wind	0.9	0.9	1.1	1.1	2.0	2.0
Cross flow - equal area openings 1m height separation - no wind	0.6	0.6	0.8	0.8	1.3	1.3
Opening with stack*	0.2	n/a	0.3	n/a	0.6	n/a
Roof terminal at 4m height – inlet area on windward face	.3		.3		.6	
- cross-sectional area of complete duct		1		1.3		2.3

*Note: stack height 5m, stack opening 1 m²

Table 9 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 0.2 m² to more than 3 m² 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.

From the results of this preliminary set of calculations with ClassVent the most attractive option without the use of a stack is the provision of openable areas on opposite sides of the classroom with some vertical separation. This design solution is typical of a clerestory design commonly used in schools and can be a highly effective strategy providing a combination of stack effect and wind

driven crossflow. Therefore the calculations can be revisited in ClassVent to provide the openings under different wind speed conditions as shown in Tables 10 and 11 below.

Table 10 ClassVent case study results for cross and stack vent design at two local wind speeds

Design condition	Winter		Mid season		Summer	
	Area 1 (m ²)	Area 2 (m ²)	Area 1 (m ²)	Area 2 (m ²)	Area 1 (m ²)	Area 2 (m ²)
Cross flow - equal area openings 1m height separation - no wind	0.58	0.58	0.75	0.75	1.33	1.33
Cross flow - equal area openings 1m height separation – 1.5m/s wind	0.36	0.36	0.4	0.4	0.4	0.4
Cross flow - equal area openings 1m height separation – 3.0m/s wind	0.21	0.21	0.22	0.22	0.23	0.23

Table 11 ClassVent case study results for roof terminal at 4m height at two local wind speeds

Wind Speed (m/s)	Inlet area on windward face (m ²)	Cross-sectional area of complete duct(m ²)
1.5	0.4	1.58
3.0	0.2	0.79

Although the default value for wind speed is 1.5 m/s, as can be seen when assuming a wind speed of 3m/s the ventilation areas for summer conditions are very much reduced and may be more easily accommodated in the façade and provided by a more controllable device. The selection of an appropriate wind speed should take into account the local weather conditions and exposure of the site of the school.

If roof terminals are a potentially viable option then guidance and design advice may be sought from the manufacturers of such devices. There may also be a benefit in terms of reducing noise ingress from external sources.

7.3.2 Design Solution

Based on the above calculations two provisional design solutions could be considered to test for architectural integration. These are:

Single sided high and low openings - by vertical sliding sash windows

From reference to Table 9 this solution will require high and low equivalent areas of 1.7 m² to provide the summer time ventilation rate of 8 l/s per person based on zero wind speed. For vertical sliding sash windows it may be appropriate to assume that the equivalent area is approximately equal to the open area. If the window width is 1.2 m and depth 1.8 m then three of these units would be able to accommodate the required 1.7 m² at both low and high level when fully open. The winter ventilation area of 0.8 m² would be easily achievable by opening the top sashes to about 200 mm and this would avoid low level draughts. This solution would give good occupant control but may not lend itself to automatic control of the windows. This design solution would most likely easily achieve the ventilation requirements given that these figures are based on zero wind speed and higher wind speeds would significantly increase ventilation.

Cross ventilation with stack effect – single window opening and opposite clerestory window vent

If the form of the classroom allows a clerestory window then cross ventilation with stack effect may be possible. Table 10 shows that equivalent areas of 0.4 m² at both high and low level would

provide the summertime ventilation at a wind speed of 1.5 m/s. To provide this equivalent area by a casement window opened to 30 degrees would need a window area of approximately 0.7 m² which could be provided by windows of very approximately 1.2 m by 0.6 m. These would need to be provided both as clerestory windows and in the opposite façade.

This solution may not provide such good occupant control and draught free ventilation as the sash windows but would lend itself more readily to automatic control and integration with a night cooling strategy should this be required.

7.3.3 Summertime Overheating and ClassCool

These design solutions may be adequate to provide sufficient external air to maintain good indoor air quality but it may not be sufficient to prevent overheating and thermal discomfort in summer. Therefore, ClassCool (see section 8) should be used to check if the selected ventilation strategy together with the other design features of the school is sufficient to control overheating. A degree of iteration may be required before the final design strategy is selected.

8 Recommended Performance standard for the control of summertime overheating

The DfES has produced the revised performance standard described below for compliance with Part L2 of the building regulations for the avoidance of summertime overheating. This standard supersedes previous standards as described in Building Bulletin 87.

8.1 Performance standard for the avoidance of overheating

Three parameters have been developed which indicate when overheating is likely to be problematic. These standards apply outside the heating season and are for the occupied period of 09:00 to 15:30, Monday to Friday, from 1st May to 30th September.

- the number of hours for which a threshold temperature is exceeded
- the degree to which the internal temperature exceeds the external temperature
- the maximum temperature experienced at any occupied time.

These performance parameters will ensure that the design of future schools is not dictated by a single factor as previously but by a combination of factors that will allow a degree of flexibility in the design of the school. They will also take account of the use of the school, for example in their choice of term dates.

The performance standards for summertime overheating in compliance with Approved document L2 for teaching and learning areas are:

- a) There should be no more than 120 hours when the air temperature in the classroom rises above 28°C**
- b) The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on average)**
- c) The internal air temperature when the space is occupied should not exceed 32°C.**

In order to show that the proposed school will not suffer overheating two of these three criteria must be met.

To assist in determining possible overheating in classrooms as indicated by these performance parameters, the ClassCool tool has been published by the DfES. ClassCool results are all derived from annual simulations using the CIBSE London Test Reference Year. Currently air temperature is used as this is the most appropriate from a historical perspective, and also ease of measurement.

The ClassCool results are presented in terms of the above performance parameters and would demonstrate compliance with the performance standards.

Note that other appropriate tools for predicting the required parameters can be used and if so should use the geographically closest CIBSE Test Reference Year and be analysed according to the guidance given in Section 8.4.2.

Note: the overheating criteria are for the thermal comfort of occupants and are not applicable for equipment such as server rooms.

8.2 General guidance on avoiding overheating

Classrooms can be subject to substantial heat gains from electrical equipment, pupils and solar gain. 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 some schools, electronic whiteboard projectors and overhead projectors are used for a large part of the school. When in use, blinds are often drawn to improve the visibility of the screen and this increases the heat load from the electric lights.

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 the design capability supply rate (Section 1.4.2) that is 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.

Ideally, 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, e.g., 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 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 (e.g., 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 can 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. Location of network servers outside occupied teaching areas will reduce incidental gains.

For much of the year, 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 façade allow entry of sunlight early in the morning, but avoid direct sunlight during midday and early afternoon when the solar radiation is more intense.

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 ventilated 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 can be 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 for boiler sizes to be very small. Earth tubes and thermal labyrinths also provide good sound attenuation.

Passive cooling, borehole cooling, earth tubes and labyrinths can all be classed as on-site renewable energy sources contributing to the 10% on-site renewables required now for major new school buildings by many local planning authorities.

Thermal insulation of roofs beyond Part L requirements has the advantage of preventing summertime overheating. Insulation can be built into the roof structure, so that it also prevents the transmission of rain noise through the roof structure into teaching areas.

8.3 ClassCool – a tool to assess overheating in classrooms

8.3.1 User Guide

ClassCool has been created with Microsoft Excel 2003, although it has also been tested with Excel 2000. The ClassCool tool needs **Macros** to be enabled; this can be done permanently in Excel by pulling down the **Tools** menu, select **Macro, Security**, and then select **Medium** or **Low** Security setting. The interface for ClassCool is shown in Figure 4.

ClassCool Inputs - Please read the User Guide Sheet before inputting data. The user should only fill the cells with **white background**

This Tool has been tested with Excel 2003 and Excel2002
 This Tool needs Macros to be enabled via the menus in Tools >> Macros >> Security
 Note to the user- do not "cut and paste" cells unless using Edit/PasteSpecial/Value which will preserve the formatting of the cells

Classroom Selection by orientation and floor

Glazed Area [%]	Percentage of façade with a 23.1m ² area (between 20% and 60%) Provide your percentage figure	GF	1F	Orientation	GF	1F
		User Input	User Input		<input type="checkbox"/>	<input type="checkbox"/>
		40	<-here--> 40			
Overhang [cm]	Tick here <input checked="" type="checkbox"/>	GF	Max	1F		
					<input type="checkbox"/>	<input type="checkbox"/>
				North East	<input type="checkbox"/>	<input type="checkbox"/>
				East	<input type="checkbox"/>	<input type="checkbox"/>
	depth, South East (120cm for 100% shading of a 185cm window)	120	120	120	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	depth, South (98cm for 100% shading of a 185cm window)	98	98	98	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	depth, South West (120cm for 100% shading of a 185cm window)	120	120	120	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	depth, West (169cm for 100% shading of a 185cm window)	169	169	169	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
				North West	<input type="checkbox"/>	<input type="checkbox"/>
				North	<input type="checkbox"/>	<input type="checkbox"/>

Louvres Numbers of louvre blades, 0 to 6 6

Blinds (midpane or internal or both) Shading Coefficient: - Choose "Full", "Half", "None", or "Other" Other Other
 Value used by ClassCool 0.50 0.50
 If choosing "Other", input your value 0.5 <-here--> 0.5

g-value non dimensional Choose between No, Partial, Full solar control (between 0.68 and 0.38) Value from Tool Value from Tool Glazing Tool value
 Value used by ClassCool 0.68 0.68 0.68 0.68
 GF 1F

Casual Gains [W/m²] Between 15 W/m² and 115 W/m² User Input User Input Casual Gains Tool
 Value used by ClassCool 40 40 70 70
 if choosing "User input", input your value 40 <-here--> 40 GF 1F

Thermal Mass [W/m²K] Low (1.1 W/m²K), Medium (3 W/m²K), High (5 W/m²K), for GF Light Weight Light Weight Thermal Mass Tool
 Value used by ClassCool 1.1 1.3 3.0 2.6
 GF 1F

Day Ventilation Day Ventilation, l/sec/person - between 5 l/sec/pers and 13 l/sec/pers 8 8

Night Ventilation Light Ventilation in ach or l/sec up to a maximum of 512 l/sec (~12 ach) 6 ach 6 ach

Figure 4 ClassCool interface

8.3.2 Data Input

The user should select the orientation(s) to be investigated and fill the cells with a white background providing the parameters required by ClassCool. These parameters are:

- Glazed Area:** The available range is between 20% and 60% of façade area; note this is area of the glazing excluding frames.
- g-value:** Also known as g-solar or Solar Heat Gain Coefficient (SHGC), the g-value is specific to the glazing used and its value is available from manufacturers' data sheets. Alternatively the user can select the output from the Glazing Tool (see below).
- Overhang:** Depth of the overhang which the user can fit, up to a maximum size, which would give 100% shading at noon on a south facing window. This size is orientation specific. The overhang is assumed to be wider than the window itself, so there is no sun penetration when the solar rays are not orthogonal to the windows.
- Louvres:** Number of louvres which the user can fit as shading device. In the 100% full façade case, the windows were shaded by 6 louvres. In the 50% shading background case, only 2 louvres are needed; the user can choose intermediate values.
- Blinds:** Shading Coefficient SC (between 1 and 0.28) which the user can specify. See the "Model Description" sheet for a table of useable values. See also the Note 1 and the "workarounds" below on how to use the shading coefficient to compensate for "out of range" cases.
- Casual Gains:** Gains which can be expected in the room, to be kept within the 15 W/m² and 115 W/m² range. The user can input a figure or select the output from the Casual Gain tool (see below).
- Thermal Mass:** Admittance of the construction. The user can select the three levels used by ClassCool, provide a value, or use the Thermal Mass tool (see below).

- h) **Day Ventilation:** Value of day ventilation (in l/sec/person), to be kept between 5 l/s per person and 13 l/s per person. The day ventilation is active between 8.00am and 5.00pm.
- i) **Night Ventilation:** Value of night ventilation (between 10.00pm and 7.00am), in air changes per hour (ach) or litres per second. Maximum admissible value is 12 ach or 512 l/s.

In addition to ClassCool, three more supplementary tools - **Thermal Mass Tool**, **Casual Gains Tool** and **Glazing Tool** are provided:

The **Thermal Mass Tool** (shown in Figure 5) allows the user to calculate the thermal mass of the building, using some standard construction layouts. The user selects the layouts using a combination of radio buttons and pull down lists. Note that the building model simulated in ClassCool is 2 storey and the ceiling for the first floor is defined in the "roof" section as it is a part of the roof layout; the user can select a "ceiling" if there is another floor above the classroom. The value from the Thermal Mass Tool is shown in ClassCool and the user can either select it directly (by choosing the option in the pull down) or select "Other" and provide the input directly.

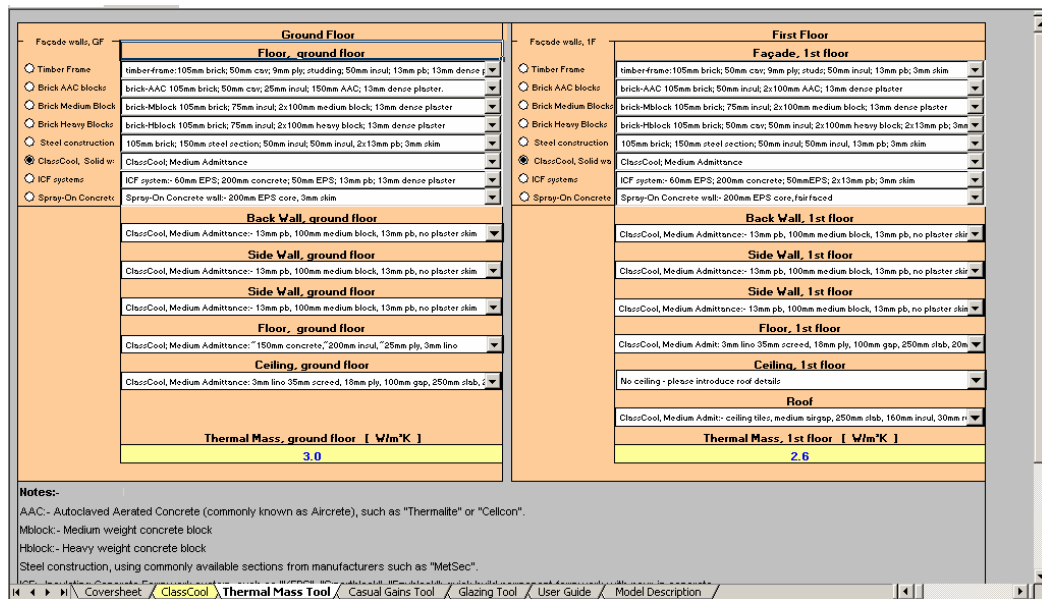


Figure 5 ClassCool interface – Thermal Mass Tool

The **Casual Gains Tool** calculates the gains which can be expected in each classroom. The user chooses between lighting loads (as individual small loads or Wattage per unit area), selects the appliances which maybe used in the classroom from a list, and finally selects the number of occupants. The tool is shown in Figure 6. The results are shown in the main ClassCool sheet where they can be selected as inputs.

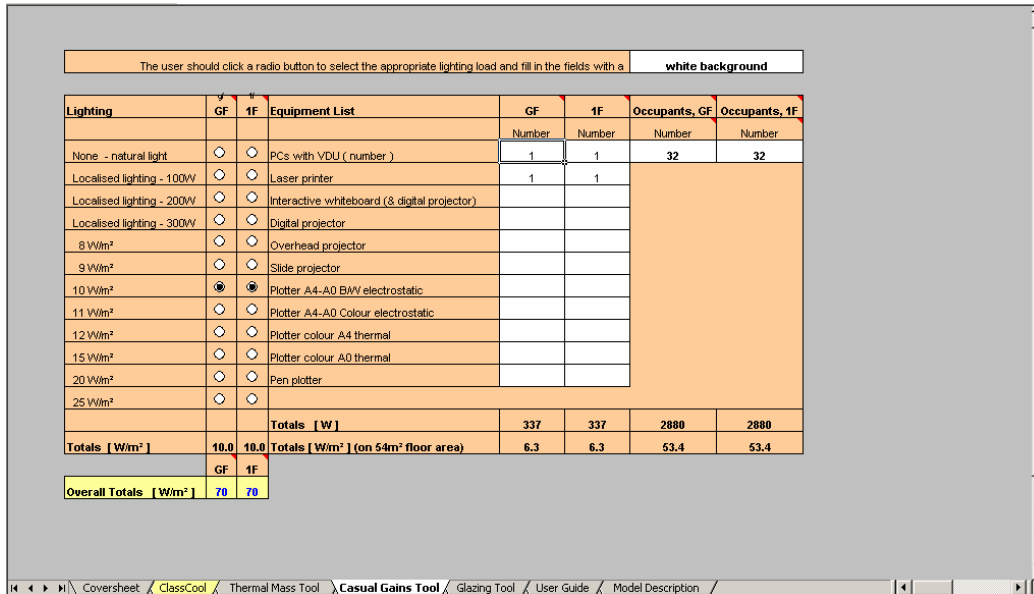


Figure 6 ClassCool interface – Casual Gains Tool

The **Glazing Tool** allows the user to select a glazing layout from some major manufacturers. The g-value for the selected glazing is shown in the ClassCool sheet. This tool is shown in Figure 7.

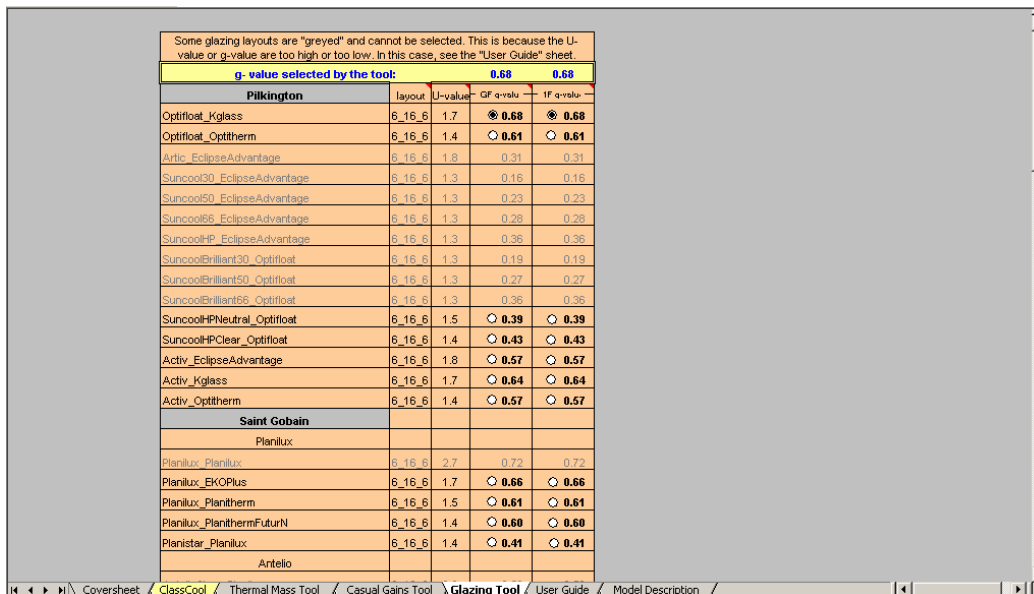


Figure 7 ClassCool interface – Glazing Tool

These supplementary tools assist the user with their input to the ClassCool tool. However, these are not comprehensive and if the appropriate data is known for other materials or equipment then these can be input to the relevant cell of the input section of ClassCool.

8.4 Presentation of the Results

ClassCool provides three types of results, all derived from annual simulations using the CIBSE London Test Reference Year, between Monday to Friday from 1st May to 30th September and during occupied hours from 9.00am to 3.30pm. Currently air temperature is used as this is the most appropriate from a historical perspective, and also ease of measurement.

a) 'hours > 28°C' [h]: A result **above 120 h** indicates serious overheating. This is the number of occupied hours when the air temperature in the classroom rises above 28°C. This period include approximately 6 weeks of 'summer', during which the class may in reality be unoccupied. This period (24th July - 9th September) produces about a third of the overheating occurrences, hence the recommendation not to exceed 120 h overheating, which is equivalent to the 80 h criterion specified in the May 2003 edition of DfES Building Bulletin 87. This figure is rounded up to the nearest multiple of 5 h.

b) 'Avg Delta T' [°C]: This is the average internal to external temperature difference during occupied hours and a result **above 5°C** indicates serious overheating. The ClassCool predictions of the temperature difference between indoor and outdoor are reasonably accurate. There is a strong correlation between overheating occurrences and ΔT , hence this is another marker for overheating which can be used. Keeping ΔT below 5°C should ensure that overheating is kept within recommended guidelines.

c) 'Max Tint' [°C]: This is the maximum internal temperature during occupied hours and results **above 32°C** indicate overheating. ClassCool is also reasonably accurate in predicting the maximum temperature which could occur in the classroom. This is very useful as it defines the quality of the overheating. Results above 35°C are not presented.

d) 'Solar Gains' (absolute [kWh] and relative to floor area [W/m^2]): The solar gains can be used to see the impact of the solar control strategies which can be adopted to control overheating. This is not a criterion for compliance.

Notes:

1. The user should not confuse the Shading Coefficient (SC) for the **blinds** with the Shading Coefficient (SC) for the **glazing**; this is a property of the glazing layout and 'somewhat superseded by the Solar Heat Gain Coefficient (SHGC) for most new applications' (*British Fenestration Rating Council - Window Energy Definitions*).
2. The simulations were carried out using the **CIBSE London Test Reference Year** weather tape, which also specify the day of the week.

8.4.1 Using ClassCool

The user should input the required data and check that the classroom is not overheating, interpreting the results as advised. If overheating

is occurring, the user may change some of the input parameters, for example:

- a) reducing the amount of solar gains; this can be done in a variety of way, by:
 - i) reducing the size of the windows
 - ii) using some "solar control" glazing - i.e. modifying the **g-value**
 - iii) using some external shading devices such as overhangs or louvres
 - iv) using internal shading devices, such as midpane or internal blinds
- b) changing the day ventilation levels, introducing a night ventilation strategy if not present already or modifying its levels – this is an area of overlap with ClassVent and some iteration between the two tools may be required to produce an acceptable design solution.
- c) increasing the thermal mass of the building, which will cause room temperature changes to occur more slowly

Note that increasing the thermal mass of the building will have very beneficial results in controlling overheating **if a proper night ventilation strategy is adopted**; this would allow more heat to be stored in the fabric of the building during the day, to be released and dissipated during the night, also counteracting a very rapid rise in temperatures when solar or casual gains are present. Increasing the thermal mass without a proper night cooling strategy may have the opposite effect, by "trapping" the heat in the room until next day; this may cause the temperature to rise out of control and produce extreme overheating.

8.4.2 Background to ClassCool

ClassCool was developed to predict the overheating response of a classroom when some basic variables are modified. These variables are: orientation, area of windows (and other factors related to solar gains, i.e. properties of the glazing used and different shading devices), casual gains, thermal mass of the building fabric, daytime and night-time ventilation levels.

The simulated model consists of 4 classroom blocks, 2 storeys high, angled at 45° to each other. Each floor has 3 classrooms with a different amount of glazed area, a corridor and three other classrooms on the opposite side. The classrooms are identical, apart from the glazed area. The four different blocks allowed the 8 basic orientations to be modelled simultaneously. The simulation used the CIBSE London TRY (Test Reference Year) weather file and the model is located in Heathrow for solar shading calculations.

Classroom Definition

The classroom is 7.7 m (width) x 7 m (depth) x 3 m (height), giving 53.9 m² gross floor area, and 161.7 m³ volume, occupied by 30 pupils, a teacher and an assistant.

The window areas modelled are 20%, 40% and 60% of the façade, which has a total area of 23.1 m².

Three different building fabrics with different level of thermal mass were modelled (see comments on each component).

The U-values used are better than the 2002 Building Regulations (and hence comply with the limits on design flexibility in Approved Document Part L2A 2006); their values and the admittance value for each component are listed in the table below.

	U-value	Fabric admittance	Fabric admittance	Fabric admittance
		Light weight	Medium weight	Heavy weight
	W/K/m ²	W/K/m ²	W/K/m ²	W/K/m ²
External walls	0.3	0.9	3.4	5.9
Floor (ground floor)	0.1	1.5	2.5	3.4
Partitions	1.5	0.8	3.1	5.4
Ceiling	1.0	1.2	3.5	5.7
Floor (1 st floor)	1.0	2.0	2.7	3.4
Roof	0.1	1.3	1.7	2.0

The 3 daytime ventilation strategies modelled were 5 l/s per person, 8 l/s per person and 13 l/s per person.

The 3 night-time ventilation strategies modelled were 0 l/s, 256 l/s, 512 l/s, the latter two being equivalent to 6 ach and 12 ach.

3 occupancy levels were used, 15 W/m², 65 W/m² and 115 W/m².

The schedule of occupancy was 9.00am to 3:30pm, 5 days a week; the period of occupancy was 1st May to 30th September.

3 different glazing layouts with different g-values were modelled, as shown in the table.

	U-value	g-value
	W/K/m ²	-
Low solar control	1.22	0.678
Medium solar control	1.22	0.522
High solar control	1.22	0.378

Two kinds of external shading devices were modelled, overhangs (shown in the picture above) and louvres. Non-external shading devices, such as mid-pane blinds or internal blinds were also modelled using a shading coefficient (SC). Typical shading coefficient from BRE, ETSU and ASHRAE (defined as IAC, interior-solar attenuation coefficient):

	BRE	ETSU	ASHRAE
Dark green plastic blind	0.81		
White venetian blind	0.61		
White cotton curtain	0.54		
Cream olland linen blind	0.40		
Midpane white venetian blind	0.44		
Internal net curtain (fine)		0.76	
Internal net curtain (open weave)		0.85	
Venetian blind (open)		0.85	
Venetian blind (closed)		0.56	
Light curtain (permanently closed)		0.49	
Heat adsorbing venetian blind (light)		0.28	
Heat adsorbing venetian blind (medium)		0.30	
Medium venetian blind			0.75
Light venetian blind			0.68
Opaque dark roller shades			0.82
Opaque light roller shades			0.40
Midpane light venetian blind			0.28
Midpane medium venetian blind			0.30

