Department for Education

Guidelines on ventilation, thermal comfort and indoor air quality in schools

Building Bulletin 101

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Summary

This document sets out regulations, standards and guidance on ventilation, thermal comfort and indoor air quality for school buildings. It replaces Building Bulletin 101, "Ventilation of School Buildings", 2006.

Section 1 provides an introduction and describes the factors that affect the design of the indoor environment of schools.

Section 2 describes the regulatory framework for schools. It gives the recommended DfE performance standards for compliance with UK regulations.

Section 3 provides a summary of regulations and recommended performance standards for school designers.

Sections 4 to 8 provide detailed non-statutory guidance on how to design schools to achieve adequate performance for ventilation, indoor air quality and thermal comfort.

Expiry/review date

This advice will next be reviewed in 2022

Who is this advice for?

This advice is for those involved in the design, specification and construction of new school buildings and the refurbishment of existing buidings. This may include contractors, architects, engineers, project managers, building users, facililties managers, governors, parents and students.

Key points

The objective is to provide guidance on the design and construction of school buildings in order to provide good indoor air quality and thermal conditions that enable effective teaching and learning.

Disclaimer

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Glossary

For definitions of building services terms such as radiant temperature, see CIBSE Guide A.

“Natural ventilation” is defined to be where the driving force for the supply of fresh air and extract of stale air is buoyancy or wind.

“Mechanical ventilation” is defined to be where the driving force for the supply of fresh air and/or extract of stale air is provided by a fan.

“Mixed mode” and “hybrid ventilation” are terms used to define ventilation that combines or switches between natural and mechanical ventilation and / or cooling systems[1].

Where the term “average” is used in this document, it means arithmetic mean.

“Kelvin” is the absolute temperature scale, ie, $20^{o}C = 293$ K

“Operative temperature” is sometimes known as “dry resultant temperature”; it takes account of the mean radiant temperature of the surfaces in the room and the air temperature in the room.

PPD Percentage people dissatisfied is used in comfort criteria.

PMV Predicted mean vote is also used in comfort criteria.

The working definition of “overheating” adopted by BB101 (Building Bulletin) is derived from that[2] developed by the Zero Carbon Hub for homes and is:

‘The phenomenon of excessive or prolonged high temperatures, resulting from internal or external heat gains, which may have adverse effects on comfort, health or learning activities’

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[1] CIBSE AM10 gives more information on mechanical, natural, hybrid and mixed mode ventilation.

[2] Overheating in homes the big picture http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingInHomes-TheBigPicture-01.1.pdf

1 Introduction

1.1 Indoor environmental quality

Ventilation is a key part of holistic design for indoor environmental quality (IEQ). The Environmental circle below describes the environmental design factors[3] that need to be addressed and the potential conflicts between the factors that need to be resolved[4].

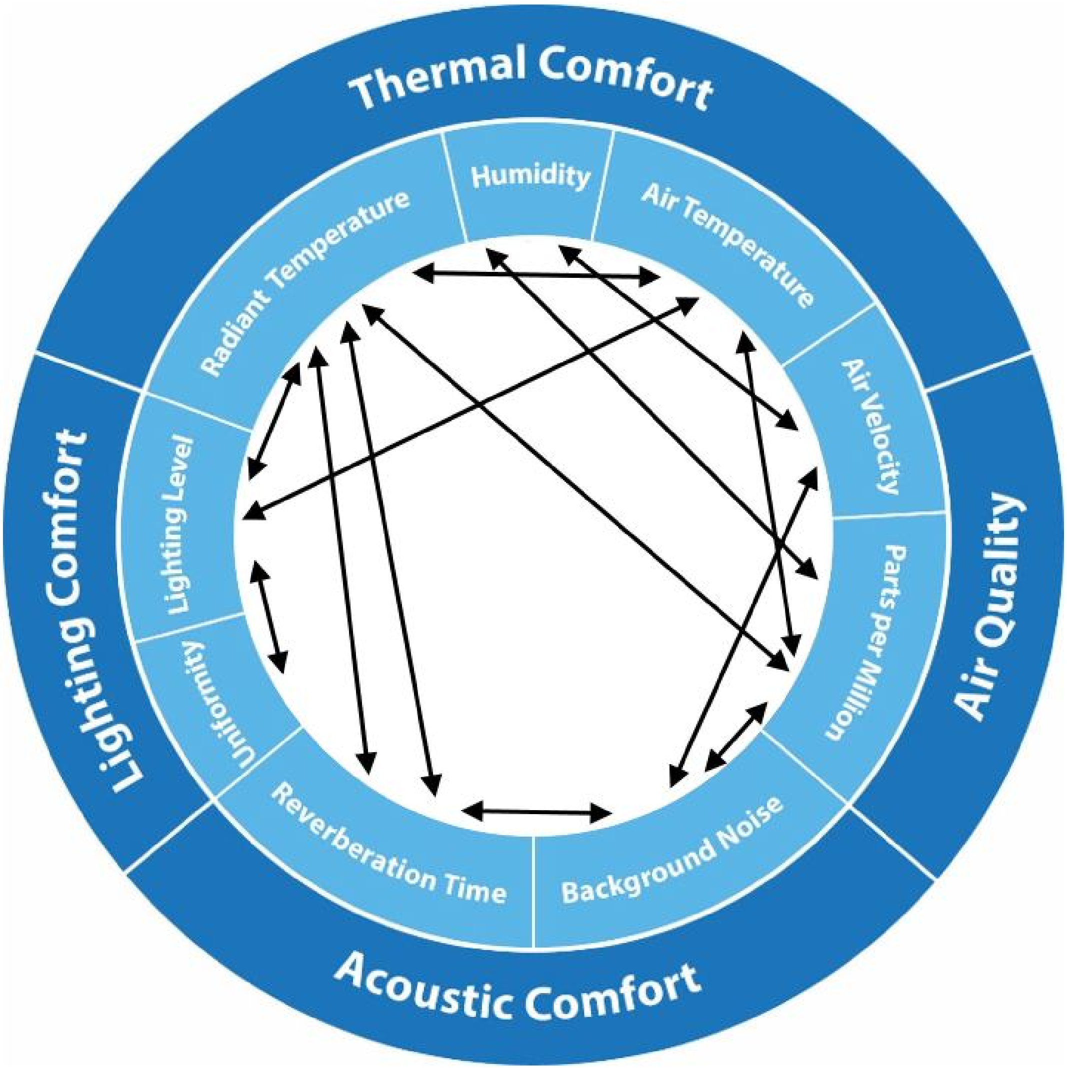

Figure 1.1 The environmental circle

[3] The environmental circle is described in the paper 'A comprehensive review of environmental design in UK schools: History conflicts and solutions' by Azadeh Montazami (Coventry University), Mark Gaterell (University of Portsmouth) and Fergus Nicol (London Metropolitan University, London).

[4] See CIBSE TM57 for a discussion of some of the design conflicts and ideas to resolve them.

Building Bulletin 93 'Acoustic Design of Schools: Performance Standards', Department for Education, 2015 and , 'Acoustics of Schools: a design guide', The Institute of Acoustics/ Association of Noise Consultants, November 2015[5] give the design criteria for acoustics.

CIBSE Lighting Guide LG5, 'Lighting in Education' gives the criteria for lighting design in schools. Technical Annex 2E: Daylight and electric lighting systems and Technical Annex 2C: External Fabric, to the EFA (Education Funding Agency) Generic Design Brief, provide detailed specifications for EFA funded projects.

A holistic multi-disciplinary approach is needed to prevent unintended consequences of design driven by low energy or other overarching design drivers[6].

The overarching factors that influence the design include:

- The adaptability of the building to changes: in occupants' needs; in outside noise levels and pollution; and future changes in climate.
- The use and maintenance of the building and its technologies
- Low energy performance
- Life cycle (cradle to grave) and operational running costs
- Sustainability

As well as the environmental design factors, it is necessary to consider the building occupants and facilities management team:

- The facilities management team need to understand the building environmental systems and controls;
- The staff need to understand the basic building operation and occupant controls; and
- The designers need to understand the occupants' needs and their behaviour in use of the space eg there needs to be adequate area provided for display; and their perceptions of thermal, visual and acoustic comfort.

Some examples of occupants' needs that impact the design are:

- Movement between teaching spaces;
- External sheltered areas for early years;
- Movement between inside and outside in early years;
- Adequate wall area left clear for display.

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[5] See References 3 and 4.

[6] International Performance Measurement & Verification Protocol, Concepts and Practices for Improved Indoor Environmental Quality, Volume II, Revised March 2002, DOE/GO-102002-1517, International Performance Measurement & Verification Protocol Committee available from www.ipmvp.org

The success or failure of the design also depends on the handover of the systems to the facilities management team and to the staff. Soft Landings[7] is essential in this and post occupancy Building Performance Evaluation (BPE) provides the necessary feedback into the specification of future design criteria.

Ventilation strategy

There are a range of ventilation strategies that can be adopted to meet the design requirements. These range from a completely natural system to a completely mechanical system. For the classrooms and practical spaces in a school, the constraints of the design will determine the type of ventilation strategy that can be used. In the majority of current designs, the general teaching spaces use hybrid or mixed mode systems that make use of a mixture of mechanical and natural ventilation.

Natural ventilation systems

The driving force for these systems is the wind and the stack effect. This includes single sided ventilation, cross ventilation or stack ventilation systems. They can employ:

- Opening windows (can be manual, automated, or a combination of both)
- Opening dampers (can be manual, automated, or a combination of both)
- Roof stacks (these can be manual or automated, but automated ones are more common)

Mechanical ventilation

These systems are fan driven. There are two types of system:

- Centralized systems which have supply and extract
- Room-based systems which have supply and extract

These systems can be coupled with cooling.

Hybrid Systems

These systems employ both natural driving forces of the wind and the stack effect and use fans to supplement these driving forces. A hybrid system is operating in mechanical mode when the driving force for ventilation is mechanical.
These types of system use natural ventilation components, coupled with systems such as:

- Fans to aid mixing in colder weather

[7] BSRIA, 2009. Soft Landings Framework

- Fans to aid higher flow rate in hotter weather
- A full mechanical ventilation system which works in tandem (at the same time) as the natural ventilation system in colder weather
- A mixed mode system with a full mechanical ventilation system which works when the natural ventilation system does not (e.g. systems which turn off in warmer weather when opening windows are used)
- A full mechanical ventilation system which works when the natural ventilation system does not, and also works in tandem with the natural ventilation components

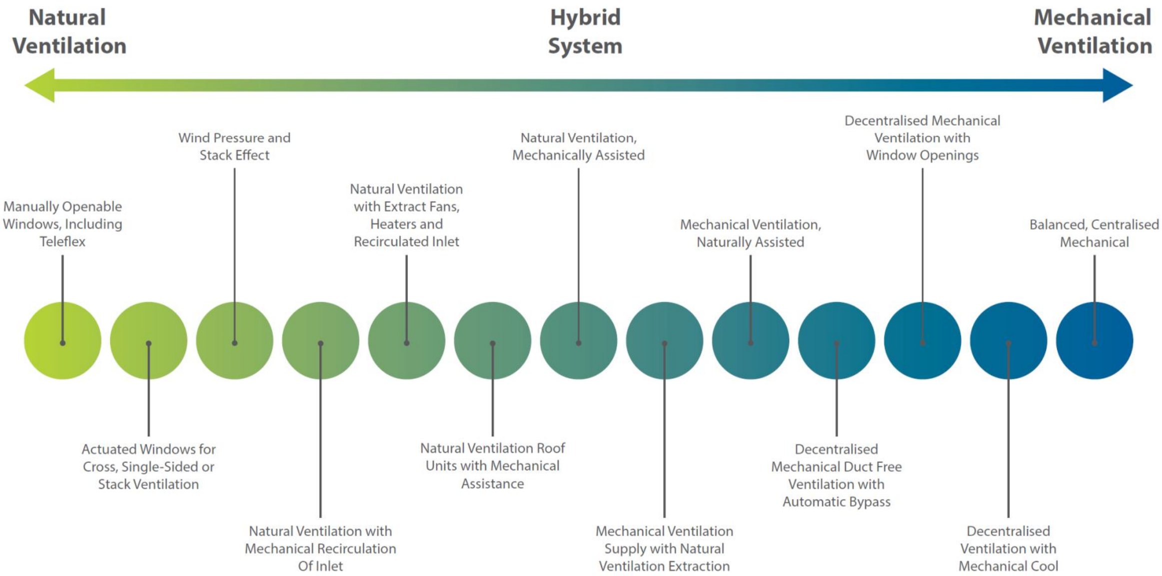

Figure 1.2 Types of ventilation system

2 Regulatory Framework

This section provides an overview of the regulations that impact upon ventilation, thermal comfort and indoor air quality in schools.

2.1 Building Regulations

UK building Regulations contain functional requirements (called standards in Scotland); such as requirements that buildings must be structurally stable, constructed and fitted to ensure fire protection, adequately ventilated for people, and reasonably energy efficient. These functional requirements are drafted in broad terms, and so documents are often issued by government, which provide practical guidance on ways of complying in more common building situations. Those documents are called Approved Documents in England and Wales, Technical Handbooks in Scotland and Technical Booklets in Northern Ireland. They are not intended to be comprehensive and so may contain references to other documents, which provide additional guidance. BB101 is one of those documents, with guidance on ventilating schools that adds to the guidance on ventilating buildings in Approved Document F, Section 3 or the Non-Domestic Technical Handbook, and Technical Booklet K. Note that following the guidance in an Approved Document, Technical Handbook or Technical Booklet does not guarantee compliance with building Regulations, but there is a legal presumption of compliance.

The requirements of Building Regulations can differ between England, Wales, Scotland and Northern Ireland. The following sections describe the requirements in England but in the devolved administrations only where they differ.

2.1.1 Part F of the Building Regulations on Ventilation

Part F of the Building Regulations applies to all buildings including schools. Requirement F1, from Part F of Schedule 1 to The Building Regulations 2010, states:

“There shall be adequate means of ventilation provided for people in the building.”

Guidance showing ways of complying with requirement F1 is contained in Approved Document F, 2010 edition (incorporating 2013 amendments). For guidance on schools, Approved Document F refers to BB101. AD F makes no provision for ventilation in respect of summertime cooling and reducing the risk of overheating.

2.1.2 Part L (AD L) on Conservation of Fuel and Power

Criterion 3 and the BRUKL method of prevention of overheating used in Approved Document L2A, 2013 edition, sets out an approach to limiting heat gains in buildings as required by paragraph L1(a)(i) of Schedule 1 to the Building Regulations. The intention is to limit solar gains during the summer period to either eliminate or reduce the need for air conditioning or reduce the installed capacity of any air conditioning system installed while ensuring that internal conditions are appropriate for the tasks being carried out. Although the compliance requirements of AD L2A only require that solar gains are limited to notional values, AD L2A recognises that for naturally ventilated buildings, limiting solar gain is not always sufficient to provide a satisfactory level of comfort and advises:

“Therefore the developer should work with the design team to specify what constitutes an acceptable indoor environment in the particular case, and carry out the necessary design assessments to develop solutions that meet the agreed brief”.

Criterion 3 and the BRUKL method are not considered appropriate methods to limit summertime overheating in schools and the method detailed in Section 7.6 of this document should be used.

It is important that overall energy usage be taken into account, to minimise the need for space heating in winter as well as reduce the requirement for summer cooling. The guidance in this document BB101 (2017) on designing schools is intended to inform this process.

Paragraph L1 (a) (ii) of Schedule 1 to the Building Regulations requires provision to be made to limit heat losses from pipes, ducts and vessels used in building services.

The Non-Domestic Building Services Compliance Guide[8], provides detailed guidance in support of AD L. It includes guidance on heating and ventilation system performance and on insulating pipework and ductwork.

2.1.3 Part C on site preparation and resistance to contaminants and moisture (including Radon)

Part C of the Building Regulations applies to all buildings including schools.

Requirement C1 of Schedule 1 to the Building Regulations 2010, states:

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[8] [8] Non Domestic building Service Compliance Guide https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453973/non_domestic_building_services_compliance_guide.pdf

"… (2) Reasonable precautions shall be taken to avoid danger to health and safety caused by contaminants on or in the ground covered or to be covered by the building and any land associated with the building."

Guidance showing ways of complying with requirement C1 is contained in Approved Document C (AD C), 2004 Edition incorporating 2010 and 2013 amendments. The recommendations in Section 2.1.3.1 are a greater provision than the minimum standard in AD C.

2.1.3.1 Radon remediation systems

Radon is an odourless, invisible radioactive gas that is produced continually in the ground from the radioactive decay of naturally occurring uranium and radium, and can be inhaled where it escapes to air. Buildings trap radon presenting an inhalation hazard to occupants. Long term exposure to high radon concentrations has been shown to increase risk of lung cancer.

Radon maps identify parts of the country (radon Affected Areas) where high levels, requiring control, are more likely. In relevant areas, building Regulations require radon protection in new buildings, extensions, etc. Existing buildings in radon Affected Areas and new buildings with radon protection should be tested for radon.

High radon levels in workplaces fall within the scope of the Ionising Radiations Regulations 1999. Established methods, entailing minor building works, are available to reduce high radon levels.

If a building has been constructed with radon protection in the form of an impermeable membrane at foundation level, it is less likely to have high indoor concentrations. This type of protection is designed to reduce the indoor radon level but it does not completely prevent the ingress of radon from the ground.

Any new building located in a radon Affected Area should be tested for radon once occupied to determine the radon level, irrespective of the presence of protection measures included at the time of construction.

If high radon levels are found, established remediation techniques are available. If the building is located in an area where radon risk is particularly high, it may already include part-provision for remediation in which case this can be completed and activated through minor building works. Further guidance is available in the BRE report BR211, "Radon: Guidance on protective measures for new buildings".

For other buildings with high radon levels, guidance is available from the BRE report FB 41 "Radon in the workplace: A guide for building owners and managers: Second edition".

Once a building has been remediated, the indoor radon levels should be measured to confirm the operation of the remediation system and the records retained. Most remediation systems use low power electrical fans that are designed for continuous long-term operation. Although underfloor ventilation systems are typical, in addition there may be air-handling systems within rooms that contradict the normal direction of flow required for the supply of outdoor air and vents that are contrary to the requirements for energy efficiency. Such systems should be labelled and checked periodically to ensure their continued operation, with an annual radon measurement. For buildings in high radon areas without remediation systems, repeat radon measurements should be made after any substantial building work.

Further guidance on radon is available from Public Health England at http://www.ukradon.org/.

Guidance for employers is available at http://www.hse.gov.uk/radiation/ionising/radon.htm and http://www.hse.gov.uk/toolbox/radiations.htm.

2.1.4 Areas covered by the English Building Regulations

The English Building Regulations, and hence the requirements of this Section of the guide apply only in England.

2.1.5 Work on existing buildings

When a building undergoes a material change of use, as defined in the Building Regulations, Regulations 5 and 6[9], the Building Regulatons apply 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. The requirements relating to radon also apply to new extensions to buildings in relevant areas.

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 K[10] (or Part N in Wales), and Part L. 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.

[9] The Building Regulations 2010 No. 2214, www.legislation.gov.uk/uksi/2010/2214/contents/made

[10] Approved Document K - Protection from falling, collision and impact

When buildings are refurbished at a significant level it is a requirement of AD L2 to upgrade thermal performance; as part of this process ventilation and summertime thermal performance should be considered.

As new windows will be more airtight than the existing ones, a like for like window replacement will not comply with the requirements of Part F, and ventilation and limiting solar gain in accordance with AD L2 need to be considered.

Installers of replacement windows in schools who are registered with a relevant competent person scheme[11] are allowed to self-certify compliance with the Building Regulations. Other installers proposing to replace windows in schools must notify a Building Control Body and will need to prove compliance with Parts F, K and L.

2.2 Health and safety legislation

A number of aspects of Health and Safety legislation apply to schools including:

- The Workplace (Health, Safety and Welfare) Regulations 2013; and
- The Control of Substances Hazardous to Health (COSHH) Regulations. See HSG 258.
- The Health and Safety (Display Screen Equipment) Regulations, 1992The Management of Health and Safety at Work Regulations 1999 apply to schools.

For the vast majority of above ground workplaces including schools, risk assessments should include radon measurements in appropriate ground floor rooms where the building is located in a radon Affected Area[12].

2.3 Workplace and School Premises Regulations

The Workplace (Health, Safety and Welfare) Regulations 2013 cover a wide range of basic health, safety and welfare issues including both ventilation and temperature in indoor workplaces. The Approved Code of Practice (ACoP), L24, 2013 gives guidance on the application of the Regulations.

Regulation 6 – Ventilation states:
"(1) Effective and suitable provision shall be made to ensure that every enclosed workplace is ventilated by a sufficient quantity of fresh or purified air.

[11] www.gov.uk/competent-person-scheme-current-schemes-and-how-schemes-are-authorised
[12] http://www.hse.gov.uk/radiation/ionising/radon.htm#legalrequirements

(2) Any plant used for the purpose of complying with paragraph (1) shall include an effective device to give visible or audible warning of any failure of the plant where necessary for reasons of health or safety."

Regulation 7 on Temperature requires that during working hours, the temperature shall be reasonable; and that excessive effects of sunlight on temperature shall be avoided.

The ACOP guidance includes the following points:

- Air that is introduced should, as far as possible, be free of any impurity, which is likely to be offensive or cause ill health. Where necessary, the inlet air should be filtered to remove particulates.
- Where necessary, mechanical ventilation systems should be provided to part or all of the building.
- Occupants should not be exposed to uncomfortable draughts.
- The fresh air supply rate should not normally fall below 5 to 8 litres per second, per occupant.
- If the temperature is uncomfortably high because of building design, all reasonable steps should be taken to achieve a reasonably comfortable temperature, for example by:
    - insulating hot plant or pipes;
    - providing air-cooling plant;
    - shading windows;
    - siting workstations away from places subject to radiant heat.
- If a reasonably comfortable temperature cannot be achieved throughout a workroom, local heating or cooling (as appropriate) should be provided. In extremely hot weather, fans and increased ventilation may be used instead of local cooling.
- In areas of the workplace other than workrooms, such as toilets and rest facilities, temperatures should be reasonable. Changing rooms and shower rooms should not be cold.
- Protection from the excessive effects of solar radiation in buildings can be achieved by introducing shading and using reflective materials. Some examples of the measures which can achieve this, either in isolation or in combination, are:
    - introducing awnings;
    - internal or external louvered blinds;
    - using dense vegetation, e.g. trees to provide shading;
    - use of anti-reflective glazing, e.g. by using films or upgrading glazing;
    - introducing overhangs or recesses to windows;

- reducing unnecessary glazing on the sides of the building receiving the most sunshine;
- improving the overall thermal mass of the building by using energy-efficient materials which allow heat to be stored and released at cooler times of the day.

Air movement is also an important control measure so do not restrict this by using the measures above.

When commissioning the design and construction of a new building, consider minimising solar effects by suitable positioning, type of glazing and the materials used – see Building Regulations.

In England, the School Premises Regulations 2012 and the Independent School Standards 2012 apply. These do not cover ventilation or temperature in schools but refer to the Workplace Regulations. In Wales, the School Premises Regulations 1999 apply and include requirements on ventilation and temperature.

2.4 DfE performance standards for teaching and learning spaces

In addition to the general ventilation requirements of Section 4 of Approved Document F 2010 (ADF), the following DfE performance standards for teaching and learning spaces apply.

1. In general teaching and learning spaces where mechanical ventilation is used or when hybrid systems are operating in mechanical mode, sufficient outdoor air should be provided to achieve a daily average concentration of carbon dioxide during the occupied period of less than 1000 ppm and so that the maximum concentration does not exceed 1500 ppm for more than 20 consecutive minutes each day, when the number of room occupants is equal to, or less than the design occupancy.
2. In general teaching and learning spaces where natural ventilation is used or when hybrid systems are operating in natural or mixed mode, sufficient outdoor air should be provided to achieve a daily average concentration of carbon dioxide during the occupied period of less than 1500 ppm and so that the maximum concentration does not exceed 2000 ppm for more than 20 consecutive minutes each day, when the number of room occupants is equal to, or less than the design occupancy.

   The system should be designed to achieve a carbon dioxide level of less than 800 ppm above the outside carbon dioxide level for the majority of the occupied time during the year, ie the criteria for a Category II building in the case of a new building (or 1350ppm above the outside carbon dioxide level, ie, a category III building, in the case of a refurbishment). See Table 6.7 for definitions of categories.

Except as described in Section 2.9 on gas safety, ventilation should be provided to limit the concentration of carbon dioxide measured at seated head height in all teaching and learning spaces.

Annex A: Carbon dioxide levels in schools gives an explanation of why the maximum design values for carbon dioxide concentration in paragraphs 1 & 2 above are different for mechanical and natural ventilation systems.

The design of ventilation openings to deliver these carbon dioxide (CO_2) levels should be based on the maximum number of occupants the space is designed to accommodate.

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

Ventilation rates for teaching areas are not sufficient for areas used for special activities, such as science, design and technology and food technology where higher rates will be required during these activities. In these practical spaces, higher levels of CO_2 are acceptable for the periods of time when Bunsen burners, cookers and other gas-fired appliances are in use. When practical spaces are used as conventional classrooms they need to provide ventilation for teaching and learning activities as described in Section 2.4. However they may also need additional ventilation during practical activities to prevent the build-up of unwanted pollutants. See Section 5.

Local exhaust ventilation (LEV) is often required to deal with specific processes or pollutant sources, such as dust or fumes, that pose a risk to the health and safety of users or affects their comfort. LEV should be provided, subject to risk assessments carried out under the Control of Substances Hazardous to Health (COSHH) Regulations 2002[13,14]. LEV is required in Science and Design and Technology practical spaces and preparation rooms and in some Art practical spaces.

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[13] See CLEAPSS Model Risk Assessments and CLEAPSS Guide G225 Local Exhaust Ventilation in D&T.

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

2.5 Ventilation of other buildings and non-teaching 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 6.3 of AD F1 2010 or EFA technical guidance.

Offices shall be ventilated in accordance with AD F.

Further guidance for particular spaces in schools is given in Section 5 and in the EFA Generic Design Brief Technical Annex 2F Mechancial services and public health engineering.

2.6 Local extract ventilation

AD F requires local extract of moisture fumes and dust. Additional ventilation is therefore needed in spaces such as laboratories, server rooms, design and technology spaces, kiln rooms, food technology rooms and kitchens, to remove fumes and heat from equipment.

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 will minimise their spread to the rest of the building. The extract ventilation may be either intermittent or continuous.

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. Further guidance is given in section 5.2.

2.7 Indoor air quality and ventilation

Achieving good indoor air quality in schools depends on minimising the impact of indoor sources of pollutants, as well as reducing outdoor pollutant ingress by effective design of the building and operation of the ventilation systems. Section 6 gives guidance on how to do this. Approved Document F (AD F) gives recommended performance levels for indoor air quality in office-type accommodation. This guidance also applies to schools. These performance levels agree with the World Health Organization (WHO, 2010) indoor air quality guidelines. The WHO indoor air quality guidelines have been used as the basis of the DfE guidance in this document as they are more comprehensive than the performance levels quoted in AD F. See Table 6.1 for an overview and comparison of the various pollutant threshold levels.

2.8 Prevention of overheating in warmer weather

In warmer weather, when the ambient temperature is high, ventilation rates to achieve adequate indoor air quality may not be suitable to remove significant thermal gains and higher ventilation rates will often be needed to avoid overheating.

Design in accordance with Section 7 will reduce the risk of overheating and ensure compliance with the Workplace Regulation 7 to reduce summertime overheating.

2.9 Gas safety regulations and standards

The primary gas regulation applying to educational establishments is the Gas Safety (Installation and Use) Regulations (GSIUR). The guidance to comply with these Regulations is provided in a number of Standards produced by IGEM covering the design, construction and maintenance of gas installations and in relevant British Standards and UKLPG documents. Detailed guidance on the application of the Regulations in schools is given in:

IGEM/UP/11 'Gas installations for educational establishments', 2010[15]. EFA Technical guidance on ventilation of specialist spaces describes a manner of installation to assist in compliance with the regulations (GSIUR) and describes how the Regulations affect the design of particular spaces in schools that are associated with gas pipework and gas appliances.

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[15] Institution of Gas Engineers and Managers, UP11: Gas Installations for Educational Establishments. - www.igem.org.uk/Publications_Information.html

IGEM/UP/1101 ‘Guidance on gas installations for the management and staff within educational establishments’ gives advice for school managers and staff.

IGEM/UP/2, edition 3 ‘Installation pipework on industrial and commercial premises.

Gas appliances in schools can be of three types.

Type A appliances are those that do not require a flue to be fitted to them and include Bunsen burners, flueless appliances, eg, some types of flueless gas fire, and most domestic and catering cookers/ranges.

Type B appliances are those appliances that require a flue pipe and are referred to as open flued appliances (such as a gas fire, a kiln or some types of larger specialist cooking appliance, eg, fish fryer ranges).

Type C appliances are referred to as room sealed (or balanced flue) and are typical of modern domestic or commercial gas boilers and may be used for heating.

The safety requirements relating to appliances and associated ventilation and interlock systems in teaching environments are covered in detail in IGEM/UP/11.

For Type B appliances: Regulation 27(4) of GSIUR requires that any mechanical extract system that is required for safe operation of the appliances must be interlocked with the gas supply. IGEM UP/19 provides more detailed requirements for interlock systems. It states that:

“For Type B appliances, environmental monitoring such as CO_2, temperature or humidity may be used in conjunction with variable speed drive (VSD) systems. However, fan flow/pressures switches or power monitoring shall always be used in conjunction with Type B catering appliances. CO_2, temperature or humidity monitoring is not acceptable as the main interlock for Type B catering appliances.”

For Type A appliances: where an appliance is served by a mechanical extract system that is required for safe operation of the appliances, IGEM UP/19 ‘Design and application of interlock devices and associated systems used with gas appliance installations in commercial catering establishments’ 2014, requires that the mechanical extract system must be interlocked with the gas supply.

IGEM UP/19 states that:

“For new installations, CO_2 monitoring would normally be used in conjunction with either a fan flow/pressure switch or fan power monitoring (see above and Sub-Section 5.2), but may be used alone with Type A appliances. For Type A appliances, environmental monitoring measuring CO_2 may be used in conjunction with other air quality sensors such as temperature or humidity to provide information to be included in an interlock system. It may also be used as part of demand control ventilation system.”

Type A appliances such as domestic cookers with their associated mechanical ventilation system(s) may therefore use CO_2 detectors or fan flow/pressures switches or power monitoring interlocks.

Section 4.2 of IGEM/UP/19 describes CO_2 and other interlock systems for catering establishments and should be consulted when designing CO_2 interlocks for food technology spaces in schools. See also EFA Technical guidance on specialist spaces. The requirements of relevant standards – such as (but not limited to) BS6173, UP/19, UP/10, etc should be followed – depending on the equipment.

In science and technology areas including food technology and design and technology spaces with only Type A appliances, it is relatively simple to use a CO_2 monitoring and interlock system. Where CO_2 interlocks are used IGEM advice is that the alarm level for CO_2 concentration should be 2800ppm and that shutdown of gas appliances should occur at 5000ppm.

At 2800 ppm supply and extract systems should either be automatically switched on or the teacher should be warned that ventilation needs to be increased. Systems to control the ventilation to keep it under 2800ppm can include individual canopies vented externally, supply air fans or opening windows. Below 2800 ppm these ventilation systems can be under teacher or user control so that noise levels can be easily controlled and energy use can be minimised.

For Type A appliances a common extract duct from extraction canopies can be used with a wall mounted CO_2 interlock system as IGEM UP/19 requires the ventilation system to be interlocked and must be in operation before gas is available to cookers.

For Type B appliances a wall mounted CO_2 interlock can be used with a common extract duct from extraction canopies but ONLY **as a secondary interlock** and not as the primary interlock which should be as described in UP/19.

Central school catering must comply with IGEM UP/19 and BS 6173. Boiler plant rooms including gas, CHP and gas fired plant must comply with UP/3, UP/10 and other associated standards for different plant types.

For schools applications, any carbon monoxide (CO) or carbon dioxide (CO_2) detection system needs to comply with a standard suitable for its use and must be regularly maintained.

Table 2.3 Summary of interlock requirements according to appliance type.

Appliance Type	Type A	Type B	Type C	Comments
Interlock System Type	**Interlock System Application**			
Flow switch or air pressure switch	Yes	Yes. *Primary interlock*	Not needed	Simple system. Does not prove environmental conditions.
Mechanical Ventilation Fan Power monitoring	Yes	Yes. *Primary interlock*	Not needed	Simple system, may be slightly better than above. Does not prove environmental conditions.
CO_2 monitoring	Yes	Yes but only with Primary interlock *Secondary interlock*	Not needed	For legal reasons not permitted alone with Type B. Provides positive proof/control of the environment for Type A. Suitable system for teaching spaces in which there are only Type A appliances. Easy to apply in schools having environmental control system.
VSD with CO_2 monitoring and control	Yes	Yes but only with a primary interlock *Secondary interlock*	Not needed	Reduces power consumption and fan noise. - Demand Controlled Ventilation. Most suitable system for teaching spaces in which there are only Type A appliances.

2.9.1 Carbon monoxide detectors

Inaccessible chimneys/flues shall be avoided. Chimneys/flues should be designed and installed so that they are in a position that allows for suitable inspection and checking in the future. UP/11 recommends CO detection systems are located in any occupied spaces through which or adjacent to which chimneys/ flues pass. This protects against leakage from within chimneys which may not always be totally accessible for visual and other inspections. However, for new installations as previously mentioned, this practice should be avoided unless suitable and detailed plans for ongoing inspection and maintenance of the chimney/flue have been developed.

UP/11 recommends that CO detectors are located adjacent to kilns, positioned in accordance with the detector manufacturer's instructions, as even during normal use they can produce significant levels of CO as part of the process of obtaining colours in the glazes.

It is not considered that there is a need for CO detection in boiler houses that have been correctly designed and ventilated in accordance with current industry practice (such as the guidance contained in IGEM UP/10). However, where a site specific risk assessment calls for such detection equipment, then it should be installed and located in accordance with the manufacturer's instructions and compliant with relevant standards.

UP 2 gives guidance on boiler rooms that may require flammable gas detection. If it is not possible to lock the boiler room, consideration should be given to the fitting of flammable gas detection in the boiler room. Particular attention needs to be given to the selection and location of flammable gas detection systems where LPG is supplied to boiler rooms. Information on Risk Assessments is given in IGEM UP/16.

CO detectors should be fit for purpose, installed and used in accordance with the manufacturer's instructions and guidance. CO alarms compliant with BS EN 50291 are specifically designed and tested for domestic and recreational spaces. This standard is not intended for detectors for use in schools or workplaces.

Detectors complying with BS EN 45544-3[16] may be used, but compliance with this standard is not compulsory and some of the requirements of this standard are intended for much more arduous industrial environments than schools. The variety of applications for CO detection within **all** educational establishment departments would require the selection of the most appropriate CO sensor/detector for that location. For example, it could be that a detector declaring compliance with only some aspects of BS EN 45544-3 would be appropriate within a boiler room adjacent to a corridor. Whereas more of the requirements or clauses might be relevant for a more process combustion orientated location.

CO detectors in new installations should be hard wired.

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[16] BS EN 45544-3, Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours - Part 3: Performance requirements for apparatus used for general gas detection.

2.9.2 Carbon dioxide detectors

Detectors that are designed to operate in commercial catering environments shall be used in catering kitchens and food technology rooms. They are required to give an audible alarm and be linked with an automatic gas shut off system, which will be fail-safe and require manual intervention in order to restore the gas supply. Detectors must be hard wired and installed in accordance with manufacturer's instructions.

Where CO_2 monitors are employed as part of the ventilation control or alarm strategy; the monitors shall be placed in an area that reflects the general CO_2 levels within the practical area or cooking area. Typically they should be fitted horizontally between 1 m and 3 m from the cooking or practiocal areas and approximately 2.5 m above floor level. They should not be located in high velocity air streams such as close to the edge of a canopy or adjacent to an air supply or

3 Summary of Regulations and guidance

Table 0.1 Summary of Regulations and guidance

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
Indoor air quality Ventilation rates	Sufficient outdoor air should be supplied to general classrooms to maintain the average occupied CO_2 levels to 1000ppm/1500ppm Section 2.4	CIBSE Guide A Table 1.5 - Filtration grade G4-G5 for protection of mechanical ventilation with heat recovery. Ventilation for particular areas and activities. Section 5 Demand controlled ventilation using temperature and carbon dioxide sensors. Monitoring and logging performance using CO_2 sensor/logger – Section 4.8, EFA Generic Design Brief, Annex 2I: Controls	EN 13779 for higher filter specifications that may be required in polluted areas.
Indoor air quality Pollutant levels	AD F Appendix A gives maximum recommended pollutant levels	Position of exhausts and incoming air vents to prevent ingress of external pollution sources Section 4.4	World Health Organisation (WHO, 2010) indoor air quality guidelines give more up to date maximum pollutant levels than AD F and covers more pollutants. Section 6 National Air Quality Standards: Consideration of measures to reduce pollutant levels where

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
	EH40 gives maximum Workplace exposure levels Radon concentration threshold is specified in the Ionising Radiations Regulations 1999; above which the Regulations apply.	Building Research Establishment (BRE) report BR211: guidance on areas where radon protection may be needed.	they exceed the NAQS. How to meet Planning requirements for Air Quality in Air Quality Management Areas Reducing indoor air pollutant sources: Specification of low pollutant emitting Fixed Furniture and Equipment Section 6.? Consider suitability of external air as a supply of outdoor air, position of vents or use of filters may be required. See section 6.5 including Section 6.5.2 for filter specifications. Best practice is to follow the latest WHO indoor air quality guidelines. See Table 6.1? BRE211 gives guidance on testing buildings with protective measures for radon. Guidance on testing other new buildings and remediating high radon levels is available from PHE at http://uk-air.defra.gov.uk/aqma/

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
Thermal comfort	Workplace Regulations	ISO 7730 is underlying comfort standard Thermal comfort for more vulnerable pupils will generally need higher category comfort criteria and particular needs of pupils must be considered. Demonstrate compliance with adaptive thermal comfort criteria in EN 15251 to prevent summertime overheating. Section 7 Overhead radiant heating panel sizing tool to limit Radiant Temperature Asymetry Section 7.4 Maximum floor surface temperatures for underfloor heating that should not be exceeded during normal occupation- Section 7.5 Central control of heating set points and run times with local control of heat emitters – Section 4.8, EFA GDB,	Risk assessments are needed for surface temperatures and Low Surface Temperature (LST) emitters may be required for more vulnerable pupils.

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
		Annex 2I: Controls Monitoring and logging performance using Temperature sensor/logger - EFA GDB Annex 2I: Controls	
Thermal comfort Summertime Overheating	AD L criterion 3	EN 15251 and CIBSE TM 52 adaptive thermal comfort criteria that apply to free running buildings – Section 7.6 anmd 7.7 CIBSE Guide A comfort criteria for air conditioned buildings apply to mechanically cooled parts of buildings ie non free running parts of buildings.	Outlets within 200mm of slab to prevent build up of hot air at ceiling level. Use of passive thermal mass in preference to active cooling systems.
Thermal comfort Prevention of cold draughts		Ensure delivery of outdoor air does not cause cold draughts. Section 7.3 Natural Ventilation systems: Use Line plume calculator to assess draughts.	

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
		Section 7.3.1 Mechancial ventilation systems and hybrid systems in mechanical mode: Use Maximum local air speed and temperature of supply air when it reaches the occupied zone to be in accordance with Section 7.3.2 and Table 7.4	
Window design Glass safety Window restrictors Location of controls	Approved Document K - Protection from falling, collision and impact	Sill heights for different age groups and Window restrictors for safety – EFA GDB Annex 2C: External Fabric Actuators for window opening need to be robust and serviceable. Openable areas using effective area as defined in Section 10.3	
Ventilation design Local extract	AD F	Extract rates in Section 5.2, Table 5.1 for gas safety are higher than those given in AD F and are based on IGEM UP/11 Toliet extract continuous not intermittent	Cooling may be required for reprographics rooms in addition to extract ventilation required to remove pollutants from photocopying machines. Table 5.1

	Regulations and statutory guidance	**Performance standards for DfE funded projects - Non statutory guidance**	**Further information and guidance – beyond the minimum performance standards for DfE funded projects**
rates		as in AD F.	
Ventilation design Position of air intakes, extracts and external louvres Minimise unintentional recirculation.	Workplace Regulations on Ventilation	Classroom based ventilation systems may require higher flow rates to allow for limited recirculation due to proximity of intake and extract grilles. Section 4, and Table 4.1. DW/172 for kitchen ventialtion systems and exhausts. Section 4.4.3 Take account of prevailing winds, flue positions, kitchen extracts, fume cupboard flues and vehicle fumes.	Use ASHRAE 62-1, ASHRAE Applcations Handbook, Chapter 45 and/or EN13779 air classes and separation distances for supply and extract where possible. Section 4.4.
Fume extract	COSSH Regulations	HSG 258 Fume cupboard flues to terminate 3m above roof level, or outside rooftop recirculation zones. See ASHRAE Applications Handbook, Chapter 45: Building air intake and exhaust design and ASHRAE 62-1 Fixed ducted fume cupboards required in	Ducted semi-mobile fume cupboards preferable to mobile recirculatory fume cupboards in schools. See CLEAPSS Publication G9a, Fume Cupboards in Schools.

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
		prep rooms.	
Gas safety	Gas Safety (Installation and Use) Regulations	IGEM Standards: IGEM/UP11 'Gas installations for educational establishments'[17] IGEM/UP1101 'Guidance on gas installations for the management and staff within educational establishments' IGEM/UP2, edition 3 'Installation pipework on industrial and commercial premises Section 4.2 of IGEM/UP/19 'Design and application of interlock devices and associated systems used with gas appliance installations in commercial catering establishments' 2014, describes CO_2 and other interlock systems for	Food technology rooms are not considered as 'commercial catering'. Environmental/CO2 monitoring suggested method of gas safety interlock in food technology rooms and science labs where there are only Type A appliances. Section 2.9 and IGEM UP 19.

[17] Institute of Gas Engineers and Managers, UP11: Gas Installations for Educational Establishments. - www.igem.org.uk/Publications_Information.html.

	Regulations and statutory guidance	Performance standards for DfE funded projects - Non statutory guidance	Further information and guidance – beyond the minimum performance standards for DfE funded projects
		catering establishments and should be consulted when designing CO_2 interlocks for food technology spaces in schools. Central school catering must comply with IGEM UP/19 and BS 6173. Boiler plant rooms including gas, CHP and gas fired plant must comply with UP10. CO detectors in rooms through which a gas flue passes even if boxed in. IGEM UP11.Section 2.9.1	

4. Design

4.1 Ventilation strategy

The choice of ventilation strategy needs to take account of: the comfort criteria to be achieved, building layout, choice of building fabric, orientation, glazing, occupancy, usage patterns, external noise levels and noise transmission(See BB93, 2015), sources of air pollution, heating and cooling provisions, room pollutants and expected solar gain.

There are a variety of types of ventilation including mixing, natural, mechanical, mixed mode and hybrid systems. In certain circumstances 100% natural ventilation can be used e.g. in high spaces. In some polluted environments 100% mechanical ventilation including filtration may be required.

During refurbishment work, opportunities should be taken to prevent summertime overheating, replace excessive glazing, provide shading, reduce solar gain and glare and increase ventilation rates.

4.2 Natural ventilation

Natural ventilation occurs either due to the buoyancy or stack effect or due to wind pressure.

Single-sided ventilation that relies exclusively on openings on one side of the room has a limiting depth for effective ventilation of typically 5.5m or 2 times the room height. Separating the openings sufficiently vertically can increase the effective depth to 2.5 times the room height.

Cross-ventilation occurs when there are ventilation openings on both sides of a space. Across the space there is a reduction in air quality as the air picks up local pollutants and heat, limiting the effective depth for ventilation to typically 15m or 5 times the room height.

To achieve cross ventilation, openable areas are needed on opposite sides of the space. This can be achieved by the use of stacks or clerestory windows. Stacks can take up valuable floor space on the floor above. See CIBSE AM10 for design guidance on wind and stack ventilation.

Calculation methods for natural ventilation to determine the effective opening areas required are described in Section 8.5.

4.2.1 Design of natural ventilation openings

For a natural ventilation system to control overheating in summertime, it will need to be designed to allow large volumes of air to flow through the teaching spaces. This can be achieved through the use of atria, cross ventilation and stacks. This provides a means of removing the internal heat gains while providing ventilation to the occupants.

4.2.2 Design of stack ventilation and atria

Cross flow, stack ventilation via an atrium, circulation space or stack is very useful for preventing overheating in schools. The buoyancy effect that arises when there is a temperature difference between the inside and outside is greater as the height of the atrium increases; this provides the potential to ventilate the building even when there is no wind.

However, incorrect atria design can lead to airflows that increase overheating rather than reduce it and can also compromise ventilation flows in a fire. Mistakes are often made at the conceptual design stage and then carried through to the final design. An effective design largely comes down to the correct relative sizing of air vents. When the opening of the atrium at high level is too small compared with the storey vents, reversed flows through the top storey or storeys are common. Conversely, exchange flows at the high-level atrium opening may occur when the atrium vent is too large; or when flows through the storeys

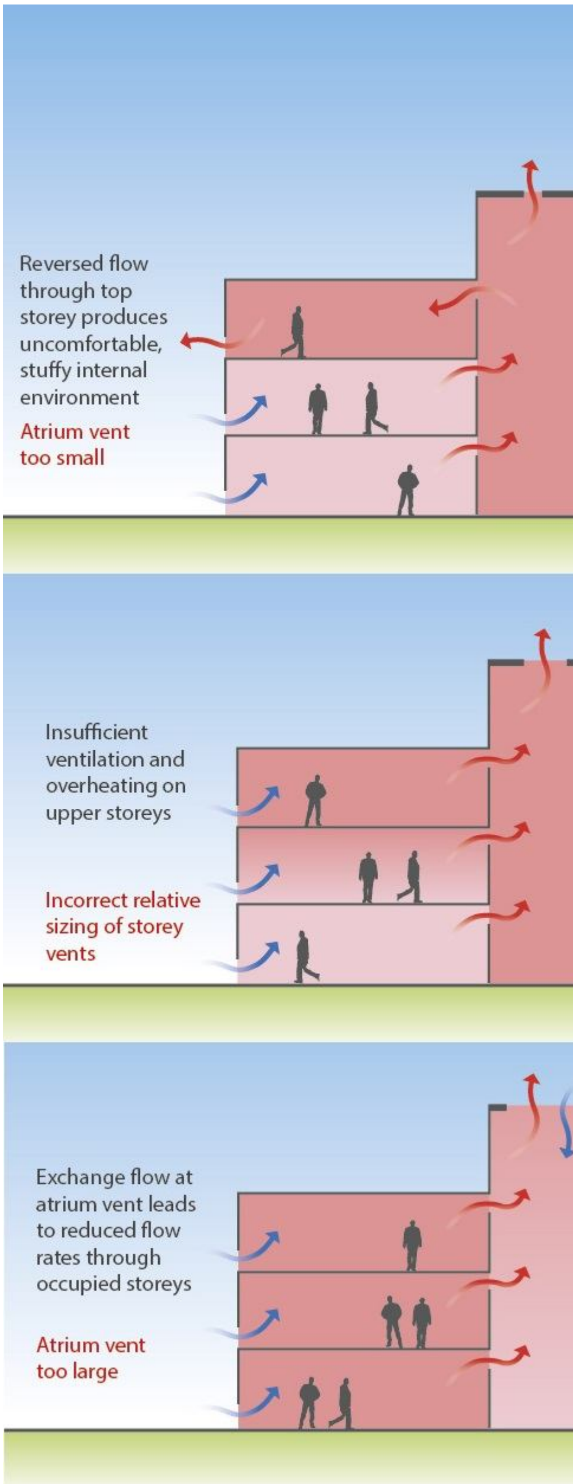

Figure 4.1 Examples of problematic flow patterns in a three storey atrium building

are restricted. Simple models of atria design have therefore been developed to help at the design stage and prevent conceptual design errors[18].

The following guidelines have been developed to help with early conceptual design of atria flow:

1. The optimum design has equal per-person vent sizes at high level in the atrium and in the top storey. This shares control between all vents in the zone of the building and ensures a forward flow on all storeys minimising the likelihood of reverse flow on the top storey.
2. Vent sizes should increase in higher storeys, to compensate for the reduction in driving stack pressure from the atrium, thereby avoiding lower flow rates or reverse flow and hence overheating on the upper storeys.
3. The atrium or ventilation stack should extend at least one storey height above the top storey to ensure an enhanced flow through all storeys. If this is not possible because of planning or budgetary constraints, the top storey should be disconnected from the atrium and a different ventilation system employed, for example, cross ventilation provided within the classroom area itself.
4. The atrium enhancement of cross flow ventilation should be greater than 1 on all storeys. For the top storey for example:

$$Atrium\ enhancement = \frac{Top\text{-}storey\ ventilation\ rate\ with\ atrium}{Top\text{-}storey\ ventilation\ rate\ without\ atrium}$$

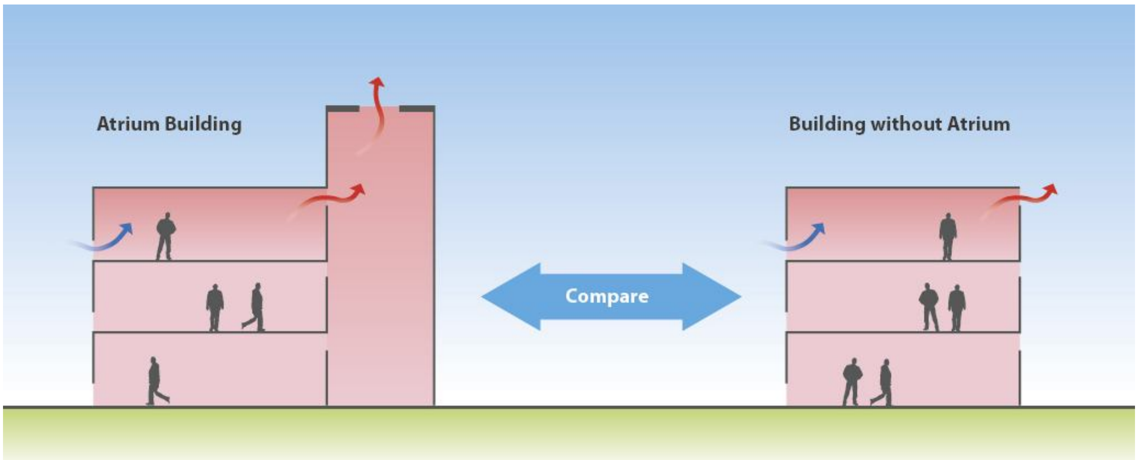

Figure 4.2 Definition of the atrium enhancement metric

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[18] A Acred 'Back to Basics', CIBSE Journal September 2015;

A Acred & GR Hunt (2013) 'Multiple flow regimes in stack ventilation of multi-storey atrium buildings', International Journal of Ventilation 12-1, 11-40;

A Acred & GR Hunt (2014) 'Stack ventilation in multi-storey atrium buildings: a dimensionless design approach'. Building and Environment 72, 44-52.

See also CIBSE AM10

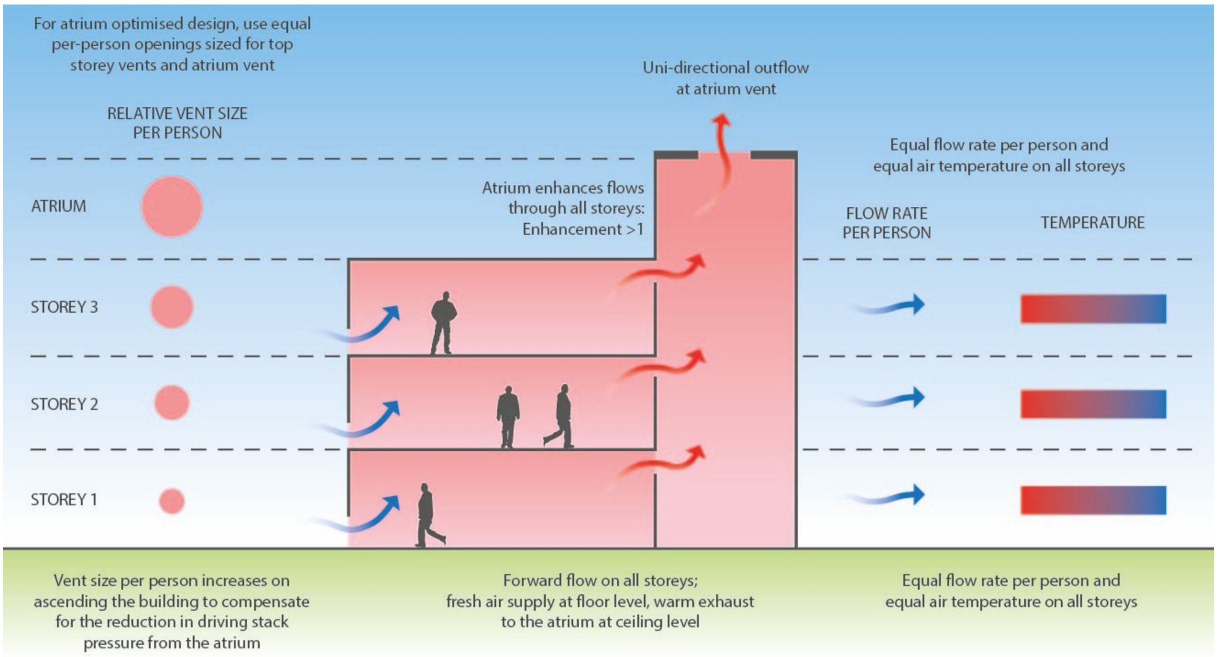

Figure 4.3 Ideal design blueprint for an atrium building.

4.3 Mechanical ventilation

Mechanical ventilation takes place when the airflow into or out of the building is driven by a fan. It can be arranged as a centralised facility with distribution ductwork, or as individual units placed directly within rooms. With heat recovery, mechanical ventilation can deliver outdoor air with only start-up space heating requirements.

Heat recovery unit heat exchangers commonly use plastic, aluminium or stainless steel. Paper heat exchangers are available but are not recommended where relative humidity can exceed 80%.

Bypass of heat recovery elements should be provided for summertime to prevent overheating.

Heat exchanger efficiencies of up to 84% on a dry-bulb basis are possible (or 92% allowing normal room humidity).

Mixing ventilation systems provide heat reuse within the space and can have similar seasonal energy efficiencies in room based ventilation systems to heat recovery units with heat exchangers. This is because in England in new buildings with high levels of thermal insulation the balance point where no heating is required with these systems is around 5^{o}C. The number of occupied hours when the external temperature is below 5^{o}C is small.

In older buildings being refurbished, the balance point can be as high as 15ºC and in this case heat exchangers can be more energy efficient as there are a large number of occupied hours when the external temperature is below 15ºC. However, this is only possible if the airtightness is improved during the refurbishment, otherwise the MVHR will not be effective.

Selection of electronic commutation (EC) fan drive motors can result in much improved specific fan powers (SFP). Together with demand control of CO_2, this reduces power demand.

4.4 Location of ventilation air intakes and exhausts

4.4.1 Location of ventilation air intakes

It is important to ensure that intake air is as uncontaminated as possible regardless of the type of ventilation system in operation. This is especially important in Air Quality Management Areas and Low Emission Zones [19] where, by definition, pollution levels of at least one pollutant have exceeded the Air Quality Standards [20]. 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 **Error! Reference source not found.**1. The guidance is greatly simplified and cannot be applied to all sites. The risks associated with specific sites may need to be assessed by an expert and may require use of physical modelling.

Table 4.1 Guidance on ventilation intake placement for minimising ingress of pollutants (**based on** Table 3.1 of Approved Document F)

Pollutant source	Recommendation
Local static sources: • Parking areas; • Welding areas; • Loading bays; • Adjacent building exhausts; • Stack	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. Consider the positioning of school parking and bus drop offs in relation to air intakes.

[19] For Air Quality Management Areas see: http://uk-air.defra.gov.uk/aqma/

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

Pollutant source	Recommendation
discharges.	
Urban traffic	Air intakes for buildings positioned directly adjacent to busy urban roads should be as high (at least 2m) 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. For buildings located one or two streets away, the placement of intakes is less critical. Pollution from railways should be considered. BS EN 13779 gives the standards that apply to the design of ventilation systems to reduce the ingress of outside air pollutants. It includes the classification of outdoor air quality and supply air classes and guidance on filtration classes. Where relevant an air quality assessment may need to accompany a planning application either using monitored data or by a survey or using pollution models such as the UK Air website.
Building features/layout: Courtyards: Street canyons:	Intakes should not be located in these spaces where there are air-pollutant discharges. If air intakes are to be located in these spaces, they should be positioned as far as possible from the pollutant sources in an open or well-ventilated area. Steps should be taken to reduce the pollutant sources e.g. parking and loading should be avoided during occupied hours as pollutants can accumulate in enclosed regions such as courtyards.
Multiple sources	Where there are a large number of local sources, the combined effect of these around the façade of the building should be considered. The façade experiencing the lowest concentration of pollutants would be an obvious choice for locating ventilation intakes, but this may require expert

Pollutant source	Recommendation
	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 pollutant sources, at a location where air is free to move around the intake.
Weather factors	In areas where wind comes from one predominant direction (e.g. in a valley location), the air intakes and outlets should point in opposite directions. In complex urban layouts, complex wind flows are likely to occur. In these cases, expert advice may be required.

Further guidance on air intakes and exhausts is given in CIBSE TM21[21] and ASHRAE Applications Handbook, Chapter 45: Building air intake and exhaust design and ASHRAE 62-1.

4.4.2 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. Exhausts should be located downstream of intakes where there is a prevailing wind direction and should discharge away from air conditioning condensers.

For dedicated room hybrid and MVHR (Mechanical Ventilation with Heat Recovery) ventilation systems the intake and exhaust can be very close together, here the design of the external louvres/damper blades can help reduce unintentional recirculation. Smoke tests and prototype installations are used to refine the design of these units and may be used to demonstrate the necessary separation of intake and exhaust air. In some cases, to allow for some recirculation airflow rates will need to be increased to achieve an adequate supply of outdoor air.

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

4.4.3 Exhaust of contaminated or polluted air and combustion products

The siting of chimneys and flues, and exhausts from kitchens, toilets and fume cupboards is important. Separation from intakes is a requirement.

CIBSE Guide B 2-96 quotes the following guidance from the ASHRAE, Handbook, Fundamentals, 2013:

Measures that should be considered to minimise re-entry from contaminated sources include:

- careful location of mechanical exhausts to avoid unintentional recirculation. For example, discharge into courtyards, enclosures or architectural screens may cause problems as pollutants do not disperse very readily in such spaces. Enclosures or architectural screens may hold contaminants within areas of flow recirculation.
- placing inlets on the roof where wind pressures will not vary greatly with direction to ensure greater stability.
- discharging exhausts vertically at high level to clear surrounding buildings, and so that downwash does not occur.
- locating wall exhausts on the upper third of a façade and intakes on the lower third to take advantage of normal wind separation on a building façade (although consideration should be given to flow recirculation that can occur on a leeward façade.
- avoiding locating inlets and exhausts near edges of walls or roofs due to pressure fluctuations. A central location on the roof is preferable for fume dispersal.

Where possible, pollutants from mechanical extracts can be grouped together and discharged vertically upwards. The increased volume will reduce the mixing of the plume and increase the 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 mechanical exhaust.

In accordance with DW/172 kitchen extract discharge points shall be positioned such that the extracted air cannot be entrained into a supply system. The ductwork shall discharge at least l.0 m above any openable window or any ventilation inlet or opening.

Flues should be high enough above any roof so as to ensure that the fumes are discharged clear of the roof recirculation zones and cannot re-enter the building or any adjoining building.

BS EN 13779 provides a graphical calculator that can be used to calculate the distance between intakes and exhausts depending on their height separation, the type of roof and the type of exhaust air, which it classifies into EHA1, EHA2, EHA3 or EHA4. This can be used for calculating stack heights and efflux velocities and separation distances for air intakes and exhausts on central air handling units and kitchen ventilation systems.

For fume cupboard exhausts and other similar exhaust systems eg from laser cutters, See Section 5.4.1.

Where stack heights are limited, eg, by planning constraints, it may be necessary to increase the plume height by increasing the efflux velocity and possibly by using a special flue terminal to entrain air into the plume to increase the plume height.

4.5 Air Quality

Where outside air pollutants exceed the levels in the National Air Quality Standards given in Table 6.1, consideration will need to be given to means of reducing pollutant levels in the indoor air. This is especially important in Air Quality Management Areas[22] (where, by definition, outside pollution levels of at least one pollutant have exceeded the Air Quality Standards) and in Low Emission Zones.

4.6 Filtration and air purification

Filtration may be needed for two reasons

1. to prevent dirt accumulating in air handling plant including on heat exchangers and ductwork.; and
2. to filter out external pollutants.

Filtering out pollutants that have health effects requires more expensive filters whereas simpler and cheaper less efficient filters can be used for protecting air handling plant. See Section 6.5.2 for further guidance on filtration.

4.7 The Coanda Effect

The Coanda effect can be usefully employed in colder weather if the temperature of the air supply jet is near to room temperature and the velocity is high as provided by a fan driven system. Grille, Diffuser and Air Handling Unit manufacturers provide advice on their products which use this effect to throw air a considerable distance in a space before it drops. The Coanda effect can overcome the difference in density

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[22] For Air Quality Management Areas see: http://uk-air.defra.gov.uk/aqma/

between the colder supply air and the room air. However if there are obstructions in the air path such as downstand beams this will prevent the systems from operating as intended and cold draughts may result. If the air speed of the supply air jet reduces, eg, due to demand control there comes a point at which the plume will detach from the ceiling and it will not reattach again until the air velocity is increased significantly. Variable speed fan controls in systems that use the Coanda effect must allow for this effect.

With single sided natural ventilation systems the Coanda effect may not be usefully employed in colder conditions, as the driving force of the wind is variable and wind speeds may be insufficient to prevent the cold, denser incoming air dropping onto occupants and causing discomfort. With cross and stack ventilation, the Coanda effect may be able to be utilised due to the smaller openings that may be required and hence higher air speeds.

4.8 Control of ventilation

It is important that ventilation is easily controllable to

- allow reduced ventilation rates when required, e.g. with low occupancy;
- allow for out of hours use;
- allow for increased ventilation in summertime;
- maintain acceptable indoor air quality; and
- avoid cold draughts and excessive heating energy consumption in the heating season.

Where possible carbon dioxide sensors should be used to save energy through monitoring and demand control of ventilation systems.

A control system with a single space temperature and CO_2 sensor with fan speed and setpoint adjustments per classroom, controlling both separate ventilation and heating systems can avoid control system conflicts which can arise where there is separate control of heating and ventilation in a room. Where TRV’s are used for local room control and there is separate automatic temperature control of the room ventilation system the TRV’s should be the lockable type and should be set so that the normal maintained room temperature cannot be exceeded due to operation of the TRV’s.

Consideration should be given to maintenance of adequate ventilation during room dim-out / blackout, and it should not be impaired by security or safety requirements. However, reduced ventilation may be acceptable for short periods.

It may be necessary to provide a timed over-ride to allow teachers to shut off room-based ventilation systems temporarily in the event of extreme wind conditions or noisy outside activities.

It is essential that occupants or teachers have control of the ventilation and understand how to use it. For the facilities management team, straightforward guidance should be provided in the building logbook and handover information. Explicit training is required on the operation of ventilation systems for the facilities management team, particularly if the system is complex or BMS controlled. For other school staff, basic training is also required at building handover and for new starters simple users' guides should be provided. This should be carried out as part of handover and soft landings.

The set points for control of ventilation are as important as the maximum design target for (CO_2).

In the case of natural and hybrid ventilation systems the control set points for the ventilation system supplying teaching spaces in schools (which can include opening windows when appropriate) should be set to achieve less than 1000ppm whenever possible.

The Technical Annex 2I: Controls to the EFA Generic Design Brief provides a detailed specification for controls for ventilation systems including recommended control strategies to be followed on EFA funded projects.

4.9 Thermal comfort

Section 7 describes the thermal comfort criteria for the different spaces and activities in a school. Section 7 uses the comfort category descriptions from BS EN 15251, see Table 7.1. Note that a space may have different comfort categories for different thermal comfort criteria. For example a sports hall has a category IV for cold draughts (see Table 7.3) but a category III for the summertime overheating risk assessment (see Table 7.7).

4.9.1 Control of cold draughts

Wherever possible frequently used external doors should have draught lobbies or unheated transition spaces configured to avoid draughts and heat losses. This is particularly important where underfloor heating is used. Where there are external doors in teaching spaces that are un-lobbied and used in colder weather it is important that the heating system has a fast response. Radiators are often used in primary school classrooms as they have a relatively fast response.

When the outside air temperature is cold it will cause discomfort if incoming air does not mix sufficiently with room air before it reaches the occupied zone. As cold outside air is denser than room air it can drop down onto the occupants and cause discomfort. There is a limit below which incoming air from high level openings driven by natural ventilation alone can mix with the internal air to prevent dumping of cold air onto the occupants. Fan assisted mixing to overcome these cold draughts or a mechanical ventilation system with a heating coil or heat recovery may be required in the heating season if opening vents cannot be designed sufficiently high, and distributed, in an occupied space to prevent cold draughts reaching the occupied zone.

In order to reduce the problem of draughts, which frequently prevents windows from being opened in classroom spaces with low-level air inlets, the EFA has developed guidelines for local thermal comfort and a calculation procedure to assess the impact of cold draughts.

See Section 7.3.1 for the guidelines and for the description of the Line Plume calculation required to assess the comfort of natural ventilation from high level openings in a space.

4.10 Design to take into account the effect of wind and rain

The design should be capable of performing in the maximum wind speeds that are regularly experienced in the area. The maximum design wind speed can be taken as either 30mph (13.4m/s) or the 95th percentile wind speed taken from the local met office 4km resolution weather map (which can be much lower than 30mph in sheltered areas).

Some ventilation systems can lead to the pressurisation of a room by wind pressure to the extent that corridor doors become difficult to open. (A 30mph wind equates to a wind pressure of 100Pa).

4.10.1 Testing of dampers and weather louvres

Air leakage of dampers and thermal performance should be tested in accordance with BS EN 1751: 2014 or BS EN 1026: 2000.[23] Note: For practical reasons where large dampers are concerned, the requirement in BS EN 1751 for the face area of the test chamber to be 7 times that of the damper may be ignored.

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[23] BS EN 1751:2014 Ventilation for buildings. Air terminal devices. Aerodynamic testing of damper and valves. BS EN 1026: 2000 "Windows and Doors - Air permeability - Test method.

External weather louvres should be provided to the appropriate weather and air flow ratings to prevent rain penetration as defined by BS 13030:2001[24].

4.11 Window design

The design of windows and associated blinds and shading devices affects ventilation and thermal comfort as windows let in solar gain as well as daylight and can be used as purpose provided openings for ventilation. They also provide views out and must be safe and secure.

The performance of windows can be compromised by the operation of windows in a way that was not intended by the designer. For example, windows intended to be open at night for night purge may be locked for security reasons. This can be avoided through proper consideration of practical, health and safety and control issues at the design stage.

Window restrictors are required on some windows for security or to prevent hazards. Detailed specifications for window and door design are provided in Education Funding Agency (EFA) GDB Technical Annex 2C: External fabric.

4.12 Thermal mass and night cooling

Slab soffits in teaching and other densely occupied spaces will often need to be exposed to provide thermal mass to absorb heat and provide night cooling. This is particularly important in hotter locations such as schools located in urban heat islands.

Requirements for exposed thermally massive building fabric

In all areas where exposed thermal mass is used to prevent overheating it is recommended that the soffits should have a light surface with a visible light reflectance of more than 70% in order to achieve adequate luminance of the ceiling.

Where an exposed soffit is to be unpainted then the reflectance of the finished surface shall be used in the lighting calculations. It is likely an unpainted surface will have a lower reflectance than a painted surface.

Any finishes to the soffit should not unduly compromise the thermal performance of the surface in relation to the radiant heat exchange. There is a balance of

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[24] BS EN 13030, 2001, Ventilation for buildings. Terminals. Performance testing of louvres subjected to simulated rain.

requirements with the need to provide sufficient acoustic absorption to reduce the reverberation time of the space.

In teaching and circulation areas exposed soffits should normally be painted matt white. Where a concrete soffit is painted, a high emissivity paint finish is required with emissivity >0.85. These paints are easily obtainable from normal paint suppliers. Special paints are not required to achieve this emissivity.

In naturally ventilated classrooms, the design should provide effective coupling of the ventilation air with thermally massive elements intended to provide passive cooling. The design should also prevent a layer of hot air being trapped at ceiling level in summertime leading to high temperatures at ceiling level.

One way to prevent this heat build up is to provide sufficient high-level free opening area, e.g., at least 1.5% (of the floor area) as geometric free area, with the top of the opening within 200mm of ceiling level. This will significantly reduce the risk of summertime overheating of the room and excess asymetric radiation from a warm ceiling. A forced air supply at this level can also mitigate the heat build up.

High-level vents should be as close as possible to the soffit can complement the need to get window heads as high as possible for good daylighting. Where concrete frame construction is used, the avoidance of down-stand perimeter beams makes this much simpler to achieve.

Walls and floors can provide useful thermal mass. In order to use the thermal mass of the floor carpet cannot be used and a vinyl or similar floor finish must be used. Blockwork walls can provide useful thermal mass but dry partitions are often preferred for walls that may need to be moved at a later date during classroom re-configuration. The thermal mass is measured by the specific heat capacity and this is usually related to the density of the material. Densities of similar building materials and their specific heat capacities vary considerably.

When assessing the benefit of thermal mass, consideration must be given to the amount of acoustic panels required to achieve the correct acoustic environment for teaching. As a rule of thumb, it can be assumed that 40% of the soffit will be hidden by acoustic panels unless an acoustician advises otherwise. Radiant heating panels and lights can also obscure the soffit. This will reduce the cooling capacity of the soffit.

Designers should consider the amount of display space and the degree to which display boards cover thermal mass. This has implications for comfort and effective night purging.

4.12.1 Thermal mass and night purge

As adaptive thermal comfort is based on operative temperature, the use of heavy weight materials such as concrete soffits will have a positive impact on the calculations. However, there is limited benefit from such a strategy unless a night purge strategy is introduced to recharge the mass using cooler night air. The purge should be controlled automatically or limited to the start and end of the night to prevent over cooling with subsequent reheat.

Night purge using fans can use considerable fan energy and the volume flow rates are lower than is possible using natural ventilation. The Specific Fan Power (SFP) for night purge fans should be considered when conducting energy calculations. The SFP will vary depending on flow rate through systems. At night it may be favourable to increase the flow rate to increase the night cooling rate. The daytime flow rates will be limited by noise level and therefore fans may vary from day to night ventilation capacity.

Night cooling of thermal mass in ceilings should be controlled to prevent over-cooling of the thermal mass by means of room temperature feedback. It has been found that it is easier and can be as effective to use room air temperature sensors with a self-learning algorithm based on temperatures achieved on previous days than to embed temperature sensors in the slab.

The security of night vents is important particularly on ground floor rooms. The impact of night purge on intruder alarms, and nuisance tripping due to insects or movement of blinds should be considered.

When modelling night purge, the heating control set point temperatures should be such that the air temperatures do not drop below the minimum permitted. This will prevent over-cooling of the space, undesirable condensation effects and over-estimating the benefit of the night purge strategy.

4.13 Energy efficiency

The energy required to temper the outdoor air in the heating season can be a significant portion of the total space-conditioning load, increasingly so as fabric insulation increases. The heating of incoming ventilation air can represent between 20% and 50% of a building's thermal load, and so should be reduced as far as possible. In the heating season, any outdoor air above that required for maintaining indoor air quality represents an energy penalty.

The design should wherever possible use the heat gains from occupancy and equipment and use this to warm incoming ventilation air.

MVHR systems, with the correct demand control can reduce heating loads by recovering the heat from internal gains. Room-based MVHR systems will need to have a minimum heat recovery efficiency factor of 75% to avoid the need to use a heater battery to achieve adequate supply air temperatures in a 100% fresh air MHVR system. The heat recovery efficiency factor should be measured in accordance with BS EN 308[25]. Heat Recovery Ventilation Units should be able to maintain their specified efficiency at both low and high speeds. Although these systems require: fan power to overcome duct resistance, filter replacements and ongoing maintenance; they have the benefit that they can provide good air quality in polluted areas when windows are closed.

4.14 Climate change adaptation

The future proofing of the indoor environment of teaching spaces is important. The use of the BS EN 15251 adaptive thermal comfort criteria instead of the temperature threshold of 28ºC used in the previous edition of BB101 (2006) provides a more rigorous test for thermal comfort and provides a more resilient design in the event of future climate change. The calculation includes August, which does not represent how schools are currently used and therefore provides an element of future proofing against climate change. It is also necessary to consider the heat island effect. Some weather files make allowance for this, eg, the latest inner city London weather file.

Climate change adaptation measures should be incorporated in planning transitional and external spaces, to reduce internal temperatures and provide outdoor shelter. Transitional spaces range from unheated atria and covered walkways to more minor spaces, such as covered verandas and porches[26]. Whilst atria can be useful, great care should be taken to avoid overheating which is a significant risk if atria are over-glazed with large horizontal glazed areas without appropriate shading and “landlocked” and have inadequate stack venting for summertime.

Shelter for outdoor space can be provided by planting as well as structures such as canopies. Canopies are usually provided for outdoor activities for early years and reception classes. Canopies are best offset from the building façade with a covered walkway connection at the doors. If they are fixed to the facade they are likely to trap hot air and prevent the ventilation strategy from working especially in summertime and will reduce the amount of daylight reaching the classroom.

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[25] BS EN 308: 1997, Heat exchangers. Test procedures for establishing the performance of air to air and flue gases heat recovery devices

[26] “Passive Solar Schools: A design Guide” includes a variety of transitional spaces, including examples of unheated atria and streets, and provides guidance on suitable depths of overhangs to prevent solar gain without unduly restricting daylight availability, DfE, Building Bulletin 79, 1994.

CIBSE KS16 contains useful advice about managing overheating and designers should inform clients of measures that can be taken to mitigate the overheating risk in areas prone to overheating such as scheduling the occupancy at cooler times of the day and relaxing the dress code, etc. CIBSE publishes guidance on the design of buildings to take account of likely changes in future climate. For the latest information, see http://www.cibse.org/

4.16 Heating system selection, sizing and control

The heating system and heat emitters should be sized to provide heat for the incoming outdoor air based on a lower ventilation rate during start up. Emitter temperatures can be increased during this period above temperatures required for thermal comfort where safe to do so. Care is needed in SEN accommodation. Sizing should consider the air infiltration, ventilation requirements and the need to overcome the thermal inertia of the building in order to achieve the required temperature in a reasonable time prior to occupation. With demand-controlled ventilation systems only infiltration needs to be included in the air load, provided the building is unoccupied during preheat. In other cases the ventilation losses should be based on a ventilation rate of 3l/s/person. If the ventilation system provides heat recovery then the ventilation losses should be calculated with reference to the temperature of the supply air.

Thermostatic radiator valves or similar control devices can be installed away from window openings to prevent more than the minimum outside air requirements being heated as a result of unmanaged windows.

All spaces should neither take too long to recover their temperature following sudden heat losses for example when external doors are opened, nor overheat due to increased heat gains, changes in occupancy or equipment heat gain, or appearance of the sun. This can be a particular problem where underfloor heating is used and/or where entrance doors are not lobbied. A lobby or buffer space is recommended and external doors to teaching spaces that are regularly used during the heating season, eg in early years and infants classrooms, should be avoided. This excludes doors for occasional use, emergency exits and doors intended for use in warmer weather only. Fast response heat emitters should generally be used in spaces with outside doors.

4.17 Life cycle and maintenance

Life cycle and maintenance of heating and ventilation systems for schools is an important consideration in the selection of equipment as school budgets are limited.

Life cycle costs should include energy, cleaning and maintenance costs. Systems with low initial capital costs may have unaffordable running costs.

Air handling units with filters may be fitted with filter alarms e.g., differential pressure sensors or hours run since last filter change and can send a fault signal to a central BMS to indicate that filters are dirty and need to be changed. An automatic ventilation system shut off can also occur if the filters have not been changed after a further pre-set run time.

Fans, filters and heat exchangers should be easily accessible for maintenance and easy to clean. Heat exchanger surfaces should be able to be inspected to ensure that they are not contaminated.

Air ducts and plenum spaces used for ventilation should be accessible and easily cleanable.

4.18 Acoustic standards

Designs should meet the DfE Acoustic Performance Standards for schools in BB93.

The main acoustic considerations are:

- Whether natural ventilation is a suitable strategy for the building taking into account the external acoustic environment. High external noise levels may preclude the use of systems based on free openings.
- If exposed concrete soffits are being used to provide passive cooling, the design should consider the reduction in the effectiveness due to acoustic absorbers and suspended ceilings that obscure the thermal mass.
- If ventilation paths are required through the building then consideration needs to be given to the level of attenuation required.

4.18.1 Indoor ambient noise levels (IANL)

Noise from building services including mechanical ventilation systems should meet the limits for Indoor ambient noise levels (IANL) given in Table 1 of Building Bulletin 93 together with the tolerances on the IANL limits given in Table 2 of BB93 for different types of ventilation system under different operating conditions

The design should show that IANLs can be achieved when the ventilation systems are operating in their normal condition; when providing intermittent boost ventilation; and when operating to control summertime overheating. A ventilation strategy may use one type of system for normal operation, and different types of system for intermittent boost and summertime overheating. Noise from ventilator actuators and dampers is covered in section 1.1.4 of BB93.

5. Ventilation for particular areas and activities

This section gives the design requirements for particular areas and activities additional to those for basic teaching and learning described in Section 2.4. Requirements for extract ventilation, e.g. from toilets, washrooms, photocopiers and printers are given in Section 5.2 .

5.1 Office accommodation

Ventilation of offices should be in accordance with AD F1 Table 6.1b, which, in the absence of excessive pollutants, requires the total outdoor supply rate to be 10 l/s/person.

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. Local extract may be required as described in Section 5.2.

5.2 Local extract ventilation

This section gives the requirements for extract ventilation, e.g. from toilets, washrooms, photocopiers and printers.

Table 5.1 Recommended minimum local extract ventilation rates

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 is required to eliminate pollutants. Air must be exhausted outside the building. If located in a separate room the room must be ventilated at the rate of 10l/s/person when occupied as for an office. These rates are those given in AD F. Cooling is required to larger reprographics machinery often found in schools, (eg with heat loads of around 2kW in use) where its use is intensive and it is located in a small room. This is due to the high heat loads produced which cannot be dealt with by extract ventilation. An alternative is to locate the machines in a circulation space, if there are no noise sensitive activities taking place in the circulation area, where the heat can dissipate. Photocopiers are often fitted with active carbon filters which limit ozone emissions. Some of these are sealed for life and others require maintenance. Information about the maintenance of photocopiers can be found in Local Authority Circular: LAC 90/2 [27].
Sanitary accommodation and washrooms.	• 6 l/s per shower head/bath; • 6 l/s per WC/urinal. These rates are those given in AD F. Individual facilities can use intermittent air-extract but combined facilities opening off circulation areas should have continuous extract with a peak rate of 6l/s/appliance; a reduced continuous background rate of 4l/s/appliance can be used where there is occupancy sensor control of the higher peak rate.
Cleaners' stores.	Extract ventilation should be provided to cleaners rooms where there are sinks or where cleaning chemicals are stored. This can be added onto toilet extract systems where they are nearby.

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

Food and beverage preparation areas (not commercial kitchens or food technology areas)	Intermittent air-extract rate of: • 15 l/s with microwave and beverages to operate while food and beverages preparation is in progress. This rate is given in AD F. This is only required where these are located in individual rooms not where they are located in larger open plan office or circulation spaces; IGEM UP/11 guidance on gas safety should be consulted in preference to AD F for extract rates for gas cookers. IGEM UP11 requires a minimum extract rate of 42l/s (150cfm) per Type A Cooker. See Section 2.8. See Section 2.8 on the gas safety regulations.
Specialist rooms (e.g. commercial kitchens, fitness rooms, science labs, food-technology areas).	See Section 5.4 on practical spaces. Local exhaust ventilation includes fume cupboards and local exhaust-hood-type vent systems that remove pollutants at source from 3D printers, laser cutters, heat bays, soldering areas, aerosol booths for spray gluing or spray painting.

Extract ventilation should be taken to the outside and provided with appropriate time and occupancy controls. Where possible extract ventilation should include a means of heat recovery.

5.3 Corridor ventilation

The minimum exhaust rate in corridors should be 1.2 l/s/m^2. This can be best provided by opening windows or vents. The cold draught criteria do not apply to corridor areas where the windows or vents are under local or manual control. Note: This area based ventilation rate in l/s/m^2 applies to spaces of any height. The equivalent air change rate per hour (ach) can be calculated from ach = (l/s/m^2 rate) x 3.6/(Room height(m)).

Corridors are areas that often overheat in schools. This is usually because they are landlocked and have very low ventilation rates. Solar gain from roof glazing and poor insulation of overhead heating and hot water pipework can cause overheating of these spaces.

These spaces are typically classified as unoccupied spaces.

Specialist ventilation systems

The following sections detail the technical requirements for a number of specialist ventilation systems within schools.

5.4 Ventilation of practical spaces

The ventilation of all practical spaces must be designed to provide adequate ventilation for the occupants. In addition, it should 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 is often required 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 affects 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 2002[28].

Further guidance on local exhaust ventilation is given in Section 0. Noise generated by extraction systems can be a problem. It should not be loud enough to prevent the teacher's voice from being heard by students, or the students' voice being heard by the teacher as this poses a significant hazard. If possible, it should be kept below 50 dB or (10 dB above the maximum Indoor Ambient Noise Level of 40 dBA). Where this is not possible, higher noise levels will only be acceptable where the teaching staff have control over the ventilation system and it can be switched off locally as required for teaching.

Fans and ventilation systems specifically installed to remove hazards (e.g. fume extractors and fume cupboards) should not be controlled by emergency stop systems fitted to gas supplies in science, food technology and design and technology spaces to isolate electrical circuits in the event of accidents. However, the gas and electrical supplies within fume cupboards should be isolated by the emergency stop.

Ventilation in practical spaces should be based on the minimum exhaust rates for pollutant control in Table 5.2. The minimum exhaust rate is an area based ventilation rate as used in ASHRAE 62-1-2013. It is the rate at which air is exhausted from a

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

space. Exhaust make-up air may be any combination of outdoor air, recirculated air, and transfer air.

Table 5.2 Minimum exhaust rates to be provided in science and practical spaces.

Room type	Area (sqm)	Minimum Required Flow rate (l/s/sqm)
Laboratories and preparation room	>70	4
Laboratories and preparation room	37-70	11.42 –(0.106 x Area) [note that this is equal to flow rate for the room of 278 l/s]
Laboratories and preparation room	<37	7.5
Chemistry store room	All	7.5
Art classroom	All	2.5
Metal/wood workshop/classroom	All	2.5
Rooms with 3D printers; laser cutters; and spray booths for spray glue or spray paint aerosols	All	5.0

Note: These area based ventilation rates in $l/s/m^2$ apply to spaces of 2.7m height or higher. The equivalent air change rate per hour (ach) can be calculated from ach = ($l/s/m^2$ rate) x 3.6/(Room height(m)). For spaces below 2.7m in height the equivalent air change rate to a 2.7m high space should be used.

The rates for sciene have been adjusted to suit school science spaces in the UK and are the result of pollutant tests carried out by EFA and CLEAPSS in science labs. The exhaust rates are needed during and following experiments and practical activities to purge the room of chemicals and other pollutants. CLEAPSS guidance[29] including the model risk assessments for pollutants (including CO_2) generated by science experiments recommends that the quantities of chemicals used in experiments are kept to the minimum possible. If CLEAPSS guidance is followed in the use of chemicals the minimum exhaust rates quoted above are sufficient for normal occupancy and dilution of pollutants in school science.

A means should also be provided in science labs to increase the exhaust either by the use of openable windows and doors or by boosting mechanical ventilation systems by at least 25% at a higher noise level under override control of the teacher.

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[29] CLEAPSS guidance is available at www.cleapss.org.uk. See References.

This allows the teacher to reduce any CO_2 levels or fumes in the room, e.g., following a difficult experiment, or a spillage, or if the alarm level of 2800ppm CO_2 is reached. It is also necessary to achieve the minimum exhaust rates given in Table 5.2 for normal experimental conditions.

The levels of CO_2 shall also comply with the gas safety requirements and their limits of 2800/5000ppm of CO_2, see Section 2.9.

Chemicals used in science should be stored in dedicated chemical storerooms. Continuous extract ventilation should be provided at all times with make-up air at low level and extraction at high level.

Noise generated by extraction systems can be a problem. It should not be loud enough to prevent the teacher's voice from being heard by students, or the students' voice being heard by the teacher as this poses a significant hazard. If possible, it should be kept below 50 dB or (10 dB above the maximum Indoor Ambient Noise Level of 40 dBA). Where this is not possible, higher noise levels will only be acceptable where the teaching staff have control over the ventilation system and it can be switched off locally as required for teaching.

Fans and ventilation systems specifically installed to remove hazards (e.g. fume extractors and fume cupboards) should not be controlled by emergency stop systems fitted to gas supplies in science, food technology and design and technology spaces to isolate electrical circuits in the event of accidents. However, the gas and electrical supplies within fume cupboards should be isolated by the emergency stop.

Food rooms should ideally be enclosed and not open plan to other teaching spaces in order to prevent dust from contaminating food. Opening windows may need fly guards to prevent insect contamination. These will impede airflow. See Section 8.5 on effective areas. If refrigerators or freezers are kept in storerooms, ventilation must be sufficient to maintain reasonably cool conditions.

In all food technology or food training areas and commercial/catering kitchens there is a need for extraction to ensure there is no build-up of potentially harmful fumes caused by gas combustion and also to deal with heat gain, water vapour, oil, grease and odours produced during cooking. Some form of mechanical ventilation will be required in food technology and preparation areas at least some of the time.

In school food rooms, where domestic ovens and or hobs are used the mechanical air extraction may not need to be switched on before the gas supply is available provided there is monitoring of the CO_2 levels within the space according to IGEM UP/11. The teaching staff/assistants must be able to (and aware of the need to) energise the mechanical/extract ventilation system and/or open windows if the

CO_2 levels increase above 2800ppm. New systems must also isolate the gas supply to appliances if the CO_2 levels increase above 5000ppm.

BS4163 provides a framework for the design and maintenance of Design and Technology practical spaces in schools and describes the safety requirements for the range of machinery and activities. It also provides an up to date set of references to standards and Regulations.

Further guidance on the ventilation of practical spaces and local exhaust ventilation is given in EFA technical guidance on the ventilation of specialist spaces.

Gas equipment in practical spaces shall be ventilated according to UP/11. See Section 2.8.

5.4.1 Design and technology

BS4163 provides a framework for the design and maintenance of Design and Technology practical spaces in schools and describes the safety requirements for the range of machinery and activities. It also provides an up to date set of references to standards and Regulations. Gas equipment in such spaces shall be ventilated according to UP/11.

Local exhaust ventilation should be provided for dust and fumes, subject to risk assessments[30]. It is required in Design and Technology practical spaces and preparation rooms and in some Art practical spaces. An air change rate of 5 air changes per hour is required for spaces where there are practical activities that require local exhaust ventilation to ensure a good background dilution rate.

Where recirculatory filtration type extraction is used on laser cutters this higher air change rate of 5 air changes per hour is required whenever the equipment could be in use. Where extract to atmosphere is employed the higher air change rate of 5 air changes per hour can be intermittent and under the control of the teaching staff.

Fume extraction is needed for but not limited to:

- hot metal work and heat treatment processes;
- laser cutters
- surface cleaning and finishing and printed circuit board manufacturing (etching).
- soldering of circuit boards; and

[30] See CLEAPSS Model Risk Assessments and CLEAPSS Guide G225 Local Exhaust Ventilation in D&T.

- for some paints and adhesives, including spray fix as used in Art rooms.

Dust extraction is required for any dust that is produced including extract from portable power tools such as routers used in KS4 construction activities.

Issues relating to the use of laser cutters

Lasers have the potential to cause significant Health and Safety problems. Laser cutters can produce harmful fumes, including VOCs many of which are carcinogenic.

Lasers must be sited in a large well ventilated room, not a store room, which is provided with an efficient fume extraction system.

There are two types of system that may be used:

- Extract to atmosphere (ETA) where fumes are removed at negative pressure and discharged through an external flue above roof level.
- Filtration systems that trap particulates in a fabric filter and VOCs in an activated charcoal filter. The clean air is returned into the room. These have similar disadvantages as mobile recirculatory fume cupboards.

Some recent devices have a built in VOC alarm, but older units may not.

ETA is always preferable, as there are no filters to change and therefore performance should never decrease as long as the system is working correctly.

Filtration systems must have the filters changed regularly, the interval depending upon use and size of filter. Typically, this may be once or twice per year in a school situation.

Both types of extraction systems must have an LEV (Local Exhaust Ventilation) test at no more than 14-month intervals.

The test should measure whether harmful VOCs are being emitted and potentially returned to the inside of the building.

Further guidance on LEV equipment may be obtained from CLEAPSS.

Comprehensive detailed operator training at installation and thereafter is essential.

5.4.2 Food technology

This section covers food technology areas dedicated to teaching and demonstration; catering kitchens are covered in Section 5.9. Food rooms should ideally be enclosed and not open plan to other teaching spaces in order to prevent dust from contaminating food.

Opening windows will require fly guards to prevent insect contamination unless there is mechanical ventilatlon providing filtered supply air. Fly screens are required where a ventilation system relies on natural ventilation openings at all times. In this case the resistance to air flow of the fly screens must be taken into account in calculations of effective area of openings. See Section 8 on effective area of ventilation opening areas.

If refrigerators or freezers are kept in storerooms, ventilation must be sufficient to maintain reasonably cool conditions.

In all food technology or food training areas and commercial/catering kitchens there is a need for extraction to ensure there is no build-up of potentially harmful fumes caused by gas combustion and also to deal with heat gain, water vapour, oil, grease and odours produced during cooking.

Some form of mechanical ventilation will be required in food technology and preparation areas at least some of the time.

Commercial/catering kitchens and larger commercial cooking ranges as used in vocational studies require interlocked mechanical ventilation and gas supply systems. See UP/19 and BS 6173.

In school food rooms, where domestic ovens and or hobs are used the mechanical air extraction may not need to be switched on before the gas supply is available provided there is monitoring of the CO_2 levels within the space according to IGEM UP/11. The teaching staff/assistants must be able to (and aware of the need to) energise the mechanical/extract ventilation system and/or open windows if the CO_2 levels increase above 2800ppm. New systems must also isolate the gas supply to appliances if the CO_2 levels increase above 5000ppm.

Cookers/hobs can be provided with local extraction see UP/11 or extract can be at high level from the space.

Exhaust ventilation may be in the form of individual extraction hoods, although these can obstruct student and teacher sightlines, may be noisy and consideration for speech intelligibility and the need to hear other warnings such as fire alarms is required. Exhaust ventilation rates shall be calculated taking account of room size and usage.

Where separate canopies are used above individual appliances, they should be designed to have a flow rate exceeding 150m^3/h. This figure is inclusive of the 8 l/s/person required for CO_2 control for room occupants.

During normal cooking activities noise generated by extraction systems should not be loud enough to prevent the teacher's voice from being heard by students, or the students' voice being heard by the teacher as this poses a significant hazard. It should be kept below 50 dB or (10dB above the maximum Indoor Ambient Noise Level of 40 dBA required by BB93). During purge ventilation due to high cooking loads or extreme summertime temperatures this level may be exceeded.

The room shall be kept under a slight negative pressure during cooking activities.

Displacement ventilation systems which extract the hot air from high level and supply cooler air at low level will help to remove heat gains from the occupied zone and limit the ventilation rates required during cooking activities. This is also useful in kitchens. For ventilation of domestic cookers in food technology spaces where there are up to 13 cookers in the space, UP11 suggests that supply and extract of 42 l/s (150m^3/hr) of air per appliance is considered sufficient ventilation but where displacement ventilation of high effectiveness is used this may be reduced. In these spaces the assumption is that appliances will never all be used at their full rate and will only be used with pupils for periods of less than one hour at a time. Mixed-mode mechanical/natural ventilation systems rather than full mechanical ventilation systems will probably be the most economical solution.

Heat recovery on supply and extract-systems may be helpful to minimise heat losses associated with high ventilation rates when cooker hoods are running.

Location of general room extract systems needs to be carefully considered to avoid excessive build-up of grease with provision made for ease of filter replacement/cleaning.

Whilst cookers/hobs are not in operation the ventilation standards should be as per a general teaching space. However, during cooking, the levels of CO_2 given in UP/11 shall be achieved.

Noise generated by extraction systems should not be loud enough to prevent the teacher's voice from being heard by students, or the students' voice being heard by the teacher as this poses a significant hazard. If possible, it should be kept below 50 dB or (10dB above the maximum Indoor Ambient Noise Level of 40 dBA).

5.4.3 Science laboratory and fume cupboard ventilation

This section provides a minimum specification for the design and installation of the ventilation and associated systems in science laboratories and fume cupboards within schools.

5.4.3.1 Design criteria

Science laboratories spend much of their time being used as conventional classrooms and shall be designed for such use, but require additional ventilation during experiments.

Practical experiments are carried out in science laboratories in the open teaching space as well as in fume cupboards. During design there are several aspects that need to be considered;

a. The use of Bunsen Burners.

b. Chemical fumes produced during experiments.

c. The safe and effective use of fume cupboards.

5.4.3.2 Bunsen burners

Natural gas Bunsen burners as used in school laboratories typically produce up to 700 W, using 1.2 litres of methane per minute. If burnt with an adequate supply of oxygen this produces 1.2 litres of CO_2 per minute. Therefore if 30 Bunsen burners are in use in a laboratory at the same time, this would produce 0.6l/s of CO_2. CO_2 levels can therefore be significantly elevated by the use of Bunsen burners; in a class of 30 pupils, CO_2 from 15 Bunsen burners is as high as that from respiration of 20 pupils.

Additional ventilation will be required when the whole class are using Bunsen burners or carrying out chemistry experiments that generate fumes.

5.4.3.3 Fume cupboards

Fume cupboards are needed in some laboratories and in chemistry preparation rooms. They should be installed and operated in accordance with the guidance in CLEAPSS Guide G9 and British Standards.

Semi-mobile fume cupboards (and where appropriate mobile fume cupboards) must be easily connected by science staff by means of docking stations and quick release service connections ideally set within the side of the teachers demonstration desk.

The connections shall not inhibit the safe use of the fume cupboards including for teacher demonstrations where students will need to gather round the fume cupboard.

Fume cupboards will generally balance themselves against supply and extract from natural ventilation paths in the same room, but can be adversely affected by the pressures generated by stack ventilation. With regard to mechanical ventilation that has a balanced supply and exhaust system, it is a requirement that the supply ventilation can be increased to provide 90% of the fume cupboards exhaust rate so that the room is maintained at a slightly negative pressure. The supply of incoming make-up air must compensate for extraction when ducted fume cupboards are in use.

Re-circulatory fume cupboards are not recommended for use with carcinogenic or mutagenic chemicals some of which are commonly used in schools. Fume cupboards shall therefore be of the ducted type. They shall be fixed in position in preparation rooms and able to be pulled out from the wall on flexible connections in teaching spaces for demonstration purposes. Exceptions where recirculatory fume cupboards may be used are:

- in refurbishments where there is no practical means to run an external flue; or
- where the school require mobile fume cupboards in some teaching spaces. In this case, the following numbers of fixed ducted fume cupboards should be provided: at least one in the chemical preparation room and at least one in one of the laboratories where the school teaches A level science.

If re-circulatory fume cupboards are used, the rooms in which they are located shall be ventilated to the minimum exhaust rate of 4 $l/s/m^2$ of floor area, given in Table 5.2, whenever the fume cupboards are in operation, with facility to purge vent to at least $5l/s/m^2$ as described in Section 5.4.1. New re-circulatory fume cupboards shall comply with and be installed in accordance with BS (EN) standards for re-circulatory fume cupboards. If a re-circulatory fume cupboards is used in a preparation room, it shall have a vertical upwards discharge and the room shall have extract from high level to minimise pollutants in the occupied zone.

A risk assessment to HSG 258 is required for all fume cupboard installations.

Where fume cupboards are in use, the air speed local to the sash shall be as low as practicable. BS EN 14175 - 5 requires that the velocity of ventilation air should not exceed 0.2m/s at a zone 400mm from the fume cupboard.

The Contractor shall ensure that where biology and physics classes conduct experiments where significant fumes are generated, for example, use of biological specimens that have been preserved in formaldehyde can produce significant levels of toxic fumes, a safe method of ventilation shall be provided. This may include the use of a fume cupboard. However, fume cupboards are not designed for and shall not be used to contain biological hazards such as bacteria cultures.

5.4.3.4 Preparation rooms

In chemistry preparation rooms, ventilation at the minimum exhaust rate shall be continuous during normal working hours, with an override function for use out of these hours. Additional make-up air is required when a ducted fume cupboard is switched on. Ducted fume cupboards shall be used in preparation rooms in preference to re-circulatory fume cupboards.

Airflow rates will be high in small preparation rooms and air velocity could be more than the normal face velocity of a fume cupboard in the closed position. At such high airflow rates the fume cupboard can spill chemicals therefore a long air inlet slot and careful positioning of fume cupboards relative to windows and vents is needed in a small preparation room to keep the airflow velocities down in the space and to avoid chemical fumes being drawn out of the fume cupboard into the room.

5.4.3.5 Ventilation controls

Air management systems with programmable controllers can accommodate a wide variety of room arrangements. Fume cupboard extract alongside room extract and supply shall be controlled locally to ensures air flow rates are kept at acceptable levels for varying equipment and room usage.

Supply-and-extract systems supplying the normal ventilation rate ie, when the ducted fume cupboards are off shall reuse the heat from the room by mixing or heat recovery to minimise ventilation heat losses.

Black out blinds required for physics experiments can interfere with natural ventilation paths, and therefore this needs to be considered. During black out experiments the ventilation rate can be relaxed to 5 l/s/person.

5.4.3.6 Fume cupboard exhausts

Exhausts from fume cupboards should discharge at a safe height above the highest part of the building. BS EN 14175-3 gives recommendations on the installation of fume cupboards. It recommends that the discharge should be at 1.25 times the height or 3m above the highest point of the building and the minimum efflux velocity should be 7m/s or preferably 10m/s. Where flues are lower than recommended the efflux velocity will need to be increased to overcome downdrafts.

ASHRAE Handbook—HVAC Applications states that downdrafts do not occur when the efflux velocity is high enough. This is the reason why a minimum efflux velocity of 15m/s is often used for fume cupboards and commercial kitchen exhausts.

Further guidance on fume cupboard discharge is available in ANSI/AIHA Z9.5, 2003, *American National Standard for Laboratory Ventilati*on. This standard advises that a discharge velocity of 12.7m/s (2500 fpm) prevents downward flow of condensed moisture within the exhaust stack and that it is good practice to make the terminal velocity at least 15.2m/s (3000 fpm)to encourage plume rise and dilution. Appendix 3 gives advice on the various calculation and modelling procedures available for stack sizing including those in the *ASHRAE Handbook—HVAC Applications, in Chapter 45 on* Building Air Intake and Exhaust Design. The Ashrae Applications Manual gives further advice on stack design and equations for the geometric stack design method and the exhaust to intake dilution calculation. These equations may be used to calculate stack heights and efflux velocities where a flue of the recommended height of 3m is not possible, eg, in the case of planning restrictions. The primary reason for the minimum height of 3m is to protect workers on the roof and if lower stack heights are used, barriers and management procedures need to be in place to protect workers.

CIBSE TM 21 Minimising Pollution at Air Intakes gives further information on calculation and modelling methods but the calculation methods used should be those in the ASHRAE Applications Manual[31] as these are frequently reviewed and may have been updated since the publication of TM 21.

5.5 Local exhaust ventilation systems

Guidance on LEV systems in design and technology spaces is given in BS 4163[32].

BS 4163 does not specify the type of LEV systems to be used but requires risk assessments to be carried out to decide this. It is essential that risk assessments to determine the need for LEV in D&T and the choice and provision of suitable LEV must be based on professional advice[33]. HSG258 provides more detailed information on LEV systems and legal competency requirements.

Local exhaust ventilation will be needed for most of the following applications:

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[31] ASHRAE Handbook—HVAC Applications, in Chapter 45 on Building Air Intake and Exhaust Design

32 British Standards Institute (2007) BS 4163 Health and Safety for Design and Technology in Schools and Similar Establishments – Code of Practice (AMD 11025), Revision to be published in 2014. London: British Standards Institution Bookshop. BS4163 is currently under revision and will be going to public consultation imminently – the final version should be published in September this year.

[33] CLEAPSS, The Design and Technology Association (DATA) and The Institute of Local Exhaust Ventilation Engineers (ILEVE) provide advice on design, operation and maintenance of safe systems for Science and Design and Technology including Local Exhaust Ventilation.

- 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, planning, and thicknessing;
- chemical processes, including acid pickling, plastics work, paint spraying, and engine exhaust emissions;
- working with adhesives;
- metalworking machines;
- polisher/buffing machines. These often require some form of LEV to trap and extract fibres and polishing compound (grinders less often);
- work undertaken with plastics and glass reinforced plastics (GRP);
- most CNC (Computer Numerical Control) machines have LEV, usually integral to the device. Some have an auto cut-off switch to prevent the machine from running if extraction is not on.

Important points to consider are:

- 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 risk is that a hot metal spark can become embedded in wood dust, and smoulder for some time, then ignite when the LEV system injects a flow of outdoor air.
- It is necessary to avoid creating hazardous waste by the mixing of dusts.
- The local exhaust inlet should be sited as close as possible to the source of contaminant, depending on the design of the machine, and extracted to a place, which will not cause harm.
- The risks from emptying and servicing/maintenance need to be considered. The person emptying the system can inadvertently be exposed to much higher levels of dust than the operators through poor LEV design.
- Air needs to be 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) and CNC machines require their own extraction systems. Some machines such as CNC routers and the extract systems can be very noisy and 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 can reduce noise and be more space efficient.

CLEAPSS[34] produces risk assessments for pollutants commonly used in science and design and technology. The CLEAPSS Model Risk Assessments for Design and Technology define ventilation needs for many design and technology processes. The CLEAPSS hazards specify a 'well-ventilated room' for science labs see Section 6.7. The CLEAPSS requirement for a 'well-ventilated room' may also indicate a need for local extract, or exhaust ventilation. For example, a cooker hood may be needed over a hob or a fume hood or fume cupboard when handling chemicals.

LEV systems and specifications should comply with HSE guidance including HSG 258[35]. LEV risk assessments and specifications should identify the processes, contaminants, hazards, sources to be controlled and exposure benchmarks. Exposure benchmarks should be based on EH40[36] and on CLEAPSS guidance on risk assessments for Science and Design and Technology.

Make up air should not create draughts or disturb the airflow into LEV hoods and fume cupboards. Ventilation openings should be designed to minimise such effects and they should be sited away from LEV hoods and fume cupboards.

LEV systems in work areas will fall under the Control of Noise at Work Regulations – which requires action to be taken to minimise exposure to noise, which is often a concern with LEV when installed locally to a machine, rather than as a central system.

LEV systems should also be designed to minimise noise levels so that indoor background noise levels do not disturb educational activities. Where possible, extract ducts should be run in bulkheads or above suspended ceilings to minimise noise in teaching spaces. Fans should be positioned remotely from the rooms served, both for acoustic reasons and to place as much ductwork as possible under negative pressure.

It is recommended that the noise level in teaching spaces due to Local Exhaust Ventilation equipment related to teaching activities should be kept as low as possible so that it does not interfere with the teaching and learning activities[37].

Extract air from laboratories and similar spaces should be ventilated directly to the outside and to other spaces.

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[34] CLEAPSS See www.cleapss.org.uk

[35] HSG 258 "Controlling airborne contaminants at work, A guide to local exhaust ventilation".

[36] EH40/2005 "Workplace exposure limits"

[37] Guidance on noise levels is given in the Acoustics of Schools: a design guide, November 2015, the Institute of Acoustics (IOA) and the Association of Noise Consultants (ANC).

Calibrated airflow indicators must be fitted to all new LEV systems to allow an easy way of checking that the LEV is working. An indicator or alarm should also be fitted to show if filters have blocked or failed. This can be by means of a manometer or a BMS alarm from a pressure sensor. Monitoring records should be kept and recorded as per the installation requirements and as indicated by risk assessment.

A user manual and logbook should be provided for every LEV system. This should specify the recommended level of training qualification required for operators who carry out maintenance on the LEV systems.

The design and installation of the LEV systems should be included in the CDM Health and Safety File[38] and Operation and Maintenance documents. The level of maintenance will depend on the frequency of use of the LEV equipment.

The Institute of Local Exhaust Ventilation Engineers, a division of CIBSE, provides access to competent local exhaust ventilation engineers and accredited training for those who maintain the equipment.

See references for further information sources and useful guidance on local exhaust ventilation.

5.5.1 Wood dust extract systems

There are two types of dust collection system

- centralised dust extraction; and
- smaller local units

In choosing where to employ these systems it is very important to consider the actual circumstances of a modern school teaching and learning environment. According to BS 4163 the need for an LEV system is decided following a risk assessment and the BS does not define which type of system is preferred.

The issues are complex and in differing schools, different solutions will be more appropriate. In some cases, a mixture of a centralised system for the Prep room and the more heavily used machinery and the sweep up points with additional local LEV to other machines may be the best option.

The advantages of well-designed centralised LEV systems is that they can be effective in capturing wood dust, low noise, easily maintained and cost effective and sustainable with low running costs, low energy costs and a single point collection of all dust generated. See HSE website http://www.hse.gov.uk/lev/case-studies/school-

[38] The Construction (Design and Management) Regulations 2015

case-study.htm for a case study in a school. However, in many schools with badly designed central systems; excessive noise reverberating throughout all workshops has been experienced whenever the system is switched on. The net result is significantly reduced quality of teaching and learning. The reality of intrusive noise caused by some centralised systems is that many schools seek to remove them and replace them with more flexible, local solutions. The noise nuisance to near neighbours must be considered, particularly in residential areas. Design for noise control is therefore of paramount importance. However, in some cases variable speed drives and automatic valves to open and shut dampers and machines interlocked with the LEV system so that the machines will not start without the LEV running can be fitted to reduce noise.

Guidance on operational noise will be given in Acoustics of Schools – A Design Guide to be published in 2015 by the Association of Noise Consultants and the Institute of Acoustics.

Centralised Systems

Centralised systems are ideal for material prep rooms, vocational training or site team workshops. Centralised systems with fixed ducting are relatively inflexible as the layout of machines and equipment cannot easily be changed. However Low Volume, High Velocity (LVHV) LEV centralised systems may be suitable for modern, flexible design and technology workrooms.

Centralised dust extract systems to woodworking machinery should be designed so that:

- the dust collection unit and extract fan are located so that the unit can be used quietly and can be easily and quietly emptied without disturbing class activities. This unit would ideally be located in a separate room. Sometimes this can be the prep room but it is better to locate this unit in its own room to contain the noise and dust. The shaker and fan and main branch ducts can also be located in this space so that noise ingress into teaching spaces is minimised;

- the air inlet to the plant room is acoustically attenuated to prevent noise causing significant disturbance to teaching areas via open windows, and to outside areas;

- vacuum hose connections are provided, instead of having a ‘sweeping up’ arrangement, and inertia type reels for vacuum hoses are provided in the preparation room and the students’ work area;

- automatic fire dampers are provided in the dust extract system and the associated plant room;

- the system is fitted with a variable speed fan and machinery dampers and interlocks, so that the system changes the flow rate when machines are switched on and off and allows hand tools to be connected. The interlocks provide automatic shut off of the extract system when the waste bag is full and a warning is provided to the prep room when the bag is nearly full;

- all branch ducts are designed for low resistance as described in HSG 258.

Local Systems

LEV systems local to individual machines can be interlocked with the machines so that the machines will not start without the LEV running.

Design of Systems

The HSE has observed many poorly designed LEV systems in schools that are not able to do the job required and the teaching staff and students have to work in conditions in which dust is not adequately controlled.

The use of legacy equipment is a way of keeping costs down. However as local systems have often 'developed' over time, rather than being designed as a carefully planned system, when these are carried over to a new building they can often be found to be inadequate, especially compared to newer, carefully designed systems.

All systems will need to filter the recirculated air to a safe level. In order to do this careful specification of flow rates and methods of particle capture as well as filter characteristics is required. The type of materials being used and the frequency and duration of the activities must be considered in the Risk Assessment.

If dust is produced, a Risk Assessment must be undertaken and if necessary some control measure should be put in place, this includes when the LEV systems are emptied. The risk to teaching staff and students can be significantly increased when emptying local systems. This risk must be managed.

Emptying and disposal of dust from LEV systems must be considered at the design stage. Clear management systems and proper, safe work routines including the use of PPE should be included in operation and maintenance manuals and health and safety logbooks.

CLEAPSS consider any dust to be a hazard regardless of what is being cut, if it creates dust it needs to be controlled if the risk assessment determines this.

The CLEAPSS Guidance Document L225[39] is based on published advice from the HSE, visits to school and college workshops (where measurements were made with a dust monitor and photographs taken using a dust lamp) and discussions with experienced health and safety advisers. The guidance recommends that:

- LEV systems are designed by qualified professionals;
- LEV systems must be supplied with performance data on installation. This is necessary so that subsequent testing can be compared with the performance on installation;
- details of the statutory 14 monthly LEV equipment tests is included in the O&M (Operation and Maintenance) manual and logbook (see Section 0);
- a logbook is provided to record the results of the commissioning and 14 monthly performance tests. are included in the O&M manuals and the H&S file tests;
- Workplace Exposure Limits (WEL) for wood dust (see Section 0) should be recorded in O&M Manuals and the H&S file and procedures defined to keep levels as low as reasonably practicable;
- The O&M manuals and H&S File must contain manufacturers and designers' maintenance schedules to ensure the systems perform as designed.

[39] CLEAPSS guidance L225 - LEV in Design and Technology (March 2003)

Table 5.3 Types of LEV system, reproduced from CLEAPSS Publication L225

Type	Characteristics	Noise	Advantages	Disadvantages
Fixed installations for whole area serving several machines	a. Inlets at each machine or source, possibly with dampers that can be closed when the inlet is not in use. b. Fixed ducting. c. A fixed filter or dust- collection system. d. A fan. e. An outlet that might return air to the workplace or vent it to the outside.	Depends on design. [Sound levels greater than 80 dB(A) make verbal communication difficult. Where the noise exceeds 80 dB(A) ear defenders are normally required.]	Only one dust-collection point to attend to and one filter to clean or replace. The noise is low if the fan is outside the workplace and the duct does not carry sound.	Often large plant, e.g. an extra building is needed to contain the fan and filter units. High noise levels if the fan etc. is in the workplace and/or if the ducting transmits sound. This may lead to ambient noise problems in rooms where quiet is needed. Extra electrical controls may be required to ensure that the system is operating when any one machine is in use. Teaching staff and students will need training to operate dampers. If the extraction unit fails none of the machines connected to the system can be used.
Independent installations at each machine	a. Fan unit is close to the machine producing the dust. b. Fan and machine are often electrically linked, so that the fan is powered whenever the machine is running. c. For dust control, the filter / dust-collection system is normally mounted in the same unit as the fan.	Can be a problem unless each fan unit is very quiet.	Units are often compact, being designed to fit under the bench or into the pedestal supporting the machine. Automatic starting of the dust control is easy. Failure of one unit does not affect use of any other machine.	Many dust-collection bags and/or filters to attend to. Many fans can generate much noise. The relatively small filter area and size of unit can result in the filter becoming clogged and hence a lack of efficiency. These units are unlikely to cope with large volumes of waste such as those produced by wood planning machines.

Portable systems	A mobile duct, filter, dust sack and fan unit, which can be moved between machines. The inlet may be general purpose or part of each machine.	A serious problem unless each fan unit is very quiet.	An economical solution for a workshop containing several machines with intermittent use.	General-purpose units are not always efficient and may not adequately control contaminates. Difficult to make system and machine electrically interlocked. It is then debatable whether or not the system fulfils legal requirements. There is a high risk that LEV may not be used because of the fuss of connecting up.
Extraction from portable power tools	A very flexible duct connected to a stand-alone dust collector or a small dust bag connected to the tool.	Portable power tools are often noisy anyway and the extra noise associated with the dust-collection system may be trivial.	Protection for the user. This type of system will also protect others nearby.	The dust-collection system may make the tool difficult to control. If a small dust bag is fitted, it can be filled after only a few minutes work and must be changed or emptied frequently.

Purchasing off-the-shelf units and having them installed by a technician is not recommended.

5.6 ICT suites

Heat gains in information and communication technology (ICT) suites 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 rejection.

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.

It should 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 cooling should not be needed. Passive cooling methods can accommodate most ICT loads but may be more costly than mechanical split system cooling units. ICT suites can be located on the North facade or where greater stack heights can be achieved to increase ventilation effectiveness.

5.7 Sports halls and main halls

Halls are often used for more than one activity. Some are used for occasional activities, e.g. performances once a year in primary school halls. In these cases as the events are fairly infrequent it may be that standards can be relaxed slightly.

Secondary schools use their sports halls for a range of sporting activities and they typically also use the sports hall for public exams because it can accommodate a whole year group at one time; the environmental conditions need to allow for this. Splitting up the year group and using other spaces such as the main hall and smaller PE (physical education) and drama spaces may be possible in some cases but is far more difficult for schools to manage. The environmental standards for sports halls are summarised in Table 5..

Table 5.4 Environmental standards for sports halls

Design parameters for sports halls		
	Normal maintained operative temperatures (^oC) (from Table 3.10)	**Thermal Comfort**
Sports (General)	17	TM 52, category III for sports use
Examination	20	To meet TM 52, category II for the examination occupancy profile

For the majority of the time there may only be one or two class groups in many halls e.g. 30 to 60 students using the space and much less outdoor air will then be needed to maintain the required CO_2 levels. The CO_2 rates from Section 0(for general teaching and learning spaces) apply also to sports halls.

The occupancy profile for examinations for a secondary school hall should be taken as weekdays 09:00 to 16:00 from 1st May to 8th July.

Noise levels are important during examinations and some heating and ventilation systems may be too noisy, e.g., gas fired radiant heating with the burner in the space. Radiant heating can be used effectively in sports halls but the RTA will need to be considered. See Section 0.

5.8 Ventilation in special schools and designated units

It is advisable to minimise recirculation of air in areas for children with complex health needs as recirculation increases the risk of cross-infection and the circulation of allergens.

Laundries, soiled holding or waste, and cleaners' rooms should be ventilated by means of mechanical extract with natural or mechanical make-up air.

Toilets for students with complex health needs and hygiene rooms should be ventilated by means of mechanical extract to outside, with make-up air, heated and filtered.

Toilets, showers, changing areas, laundries, cleaners' rooms and spaces holding soiled clothes or clinical waste should be mechanically ventilated to achieve a slight negative pressure relative to adjacent spaces.

Ventilation design should not compromise acoustic performance, particularly where students have additional sensitivities to noise.

Infection control

For schools where there are students with complex health needs, ventilation systems should be designed for infection control and to maintain standards of hygiene. Teaching staff/assistants should be able to control ventilation for comfort, and draughts should be minimised so as not to affect vulnerable and immobile students. Legionella is a higher risk to people with complex health needs some of whom may be immuno-compromised. Particular attention needs to be paid to legionella prevention in domestic hot water systems and in any adiabatic cooling systems in these schools[40].

In these schools where mechanical ventilation is specified filtration should be provided at a minimum quality of SUP3 (See Table 4.5 for definition of SUP3), depending on external air quality and design exposure levels, see Section 0.

The requirements for ventilation for mainstream schools are based on a typical occupant density of 30 students 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 are summarised in Table 5. below.

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[40] See CIBSE TM13 and HSE L8 L8 Legionnaires' disease. The control of legionella bacteria in water systems

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Ventilation systems should be controllable and adjustable, according to the needs of individual students. Air conditioning should be avoided but where present should be regularly maintained to minimise noise emissions and to maintain hygiene conditions.

Table 5.5 Ventilation provisions for special educational needs and special schools

Space	Capability for a minimum air change / hour (ach)	Ventilation mode - mechanical /natural/hybrid
Teaching spaces, Physiotherapy, medical and sick rooms	2 ach or 8l/s/person whichever is the greater; when occupied	Natural or hybrid systems where possible, need to be capable of controlling internal temperature and draughts.
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	Natural, hybrid or mechanical with Local Exhaust Ventilation and fume cupboards if required.
Hygiene, lavatory and changing areas, medical-inspection rooms and sick rooms	Intermittent extract of 6l/s per WC/urinal and 15l/s per shower/bath or 10ach whichever is greater.	Mechanically extracted to outside, provision should be made for make-up air, which should be heated and filtered. Heat recovery is recommended. The systems should be separate from any general school ventilation system.
Laundries, soiled holding or waste, cleaners rooms	5 ach	Mechanical extract with provision for natural, hybrid 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.

Note: The area based ventilation rates in l/s/m^2 in **Error! Reference source not found.**.3 apply to spaces of 2.7m height or higher. The equivalent air change rate per hour (ach) can be calculated from ach = (l/s/m^2 rate) x 3.6/(Room height(m)). For spaces below 2.7m in height the equivalent air change rate to a 2.7m high space should be used.

Managing cross-infection

Some students in special schools may be very vulnerable to infection. In these cases Health Technical Memoranda, specifically HTM 03-01 Part A[41], published by NHS Estates should be consulted and it is essential that infection control policies are in place and implemented. Managing cross-infection is a complex subject, but the risks of cross-contamination can be reduced through adequate source control. Sick rooms should be provided with full fresh air with no recirculation.

5.9 Catering kitchens

This section covers commercial and vocational kitchens where the equipment in use is similar.

Adequate ventilation is required to safeguard against the possibility of incomplete combustion.

Detailed advice on gas installations can be found in the publication 'Gas Installations for Educational Establishments', IGEM/UP/11.

Guidance on air supplies required to support combustion where gas appliances are installed is available in BS 6173: 2009.

Ventilation shall be provided and interlocked according to IGEM/UP/19 and BS 6173.

Adequate combustion air, as required by standards, 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 safe 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 competent engineer.

Where gas cooking appliances are used, a mechanical ventilation system may be regarded as a "power operated flue" as described in the Gas Safety Regulations [42], in which case it will need to be interlocked with the gas supply as required by The *Gas Safety (Installation and Use) Regulations 1998 (*GSUIR), UP/19, and BS 6173. Ventilation may need to be provided at source, by means of Local Exhaust Ventilation, in accordance with COSHH requirements. The HSE guidance note on

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[41] Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises Part A: Design and validation

42 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

ventilation of kitchens in catering establishments gives good advice, some of which is applicable to food technology rooms as well as school kitchens[43].

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

Energy consumption of kitchens and their ventilation systems varies greatly depending on the specification of kitchen equipment and its ventilation requirements. See CIBSE TM 50 *Energy Efficiency in Commercial Kitchens* for guidance on energy efficient design and benchmarks.

School kitchen ventilation

Kitchen ventilation systems should generally in accordance with DW/172. Flue heights and efflux velocities and odour control should be either in accordance with DW/172 or local planning requirments for commercial kitchens. The methods set out in DW/172 can be used to calculate the required extract air flow rate for a kitchen canopy or for a ventilated ceiling.

Dedicated supply make up air systems should be designed at 85% of the extract flow rate, however leakage paths need to be properly managed. Kitchen extract fans should be fitted with a variable speed inverter control, attenuation and grease filtration. The kitchen extract system should be interlocked with the gas supply.

The method set out in BS 6173 should be used to calculate the required ventilation to support combustion for gas appliances.

It is necessary to ensure that:

a. Sufficient ventilation is provided to safeguard against the possibility of incomplete combustion.
b. An interlock is provided between gas supply and mechanical ventilation to ensure that gas will not be supplied when an inadequate airflow rate is provided. This is for safe operation of appliances and the safety of personnel. Interlocking requirements shall comply with UP11 and UP19 and .

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[43] Health and Safety Executive (2000), *Catering Information Sheet No 10, http://www.hse.gov.uk/pubns/cais10.pdf* and
Health and Safety Executive (2000), *Catering Information Sheet No 11, http://www.hse.gov.uk/pubns/caterdex.htm*

c. The system is fully compliant with the requirements set out in IGEM UP/11 "Gas Installations for Educational Establishments" UP 19 and other IGEM standards.
d. The discharge from the exhaust of the system is appropriately positioned.
e. The discharge from the exhaust of the system does not cause discoloration or damage to any part of the building structure or any noise or odour problem to neighbouring rooms or properties.

HSE Catering Information Sheet 23 details the risk assessment process that should be applied for refurbishment and upgrading of installations that do not meet the requirements for new installations.

Grease filters

Grease filters, preferably of the removable baffle type, should be installed so that they are accessible for cleaning and maintenance. Grease extracted by the ventilation system should be collected and removed so that it does not accumulate in either the canopy or the ductwork system.

Cooking odours can be generated as a product of the combustion of animal and vegetable matter which results in a particulate and gaseous mixture. These molecules can be too small to be removed by filtration.

DW/172 and Defra guidance[44] summarise the available odour control and filtration and noise control technologies along with their advantages and disadvantages. The priority should be to provide simple technologies that are easily maintained by the school and to provide adequate efflux velocity and flue height to provide good dispersal where possible rather than to employ expensive odour control and filtration systems with a lower flue height and efflux velocity. In general the flue shall terminate at least 1m above the roof or any air inlet at an efflux velocity of at least 10m/s as recommended in DW/172.

Carbon dioxide detectors

Hard wired detectors that are designed to operate in commercial catering environments should be used. They are required to give an audible alarm and be linked with an automatic gas shut off system, which will be fail-safe and require manual intervention in order to restore the gas supply. Detectors must be installed in accordance with manufacturer's instructions.

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[44] Guidance on the Control of Odour and Noise from Commercial Kitchen Exhaust Systems, DEFRA, 2005.

Where CO_2 sensors are required, they shall be placed in an area that represents the general CO_2 levels within the room. They should be fitted horizontally between 1 m and 3 m from the cooking areas and 2.5 m above floor level. They should not be located in the path of high velocity air streams such as close to the edge of a canopy or adjacent to an air supply or extract position.

6. Indoor and outdoor air quality

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 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 reducing pollutant ingress by effective design and operation of the building and the ventilation system as well as minimising the impact of indoor sources.

6.1 Indoor and outdoor air quality guidelines and UK air quality standards

WHO (WHO, 2010[45]) has published health-based guidelines and recommendations for selected indoor air pollutants, which are known for their health hazards, and are often found in indoor environments, including school buildings. WHO (2009)[46] has also published guidelines for indoor air quality related to dampness and mould.

WHO (WHO, 2010) indoor air quality guidelines aim to provide a uniform basis for the protection of public health from adverse effects of indoor exposure to air pollution.

The issue of IAQ in school buildings cannot be properly addressed if the quality of the ambient air is ignored or overlooked. 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, 2007) [47].

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[45] World Health Organization (2010) WHO Guidelines for Indoor Air Quality: Selected pollutants. Copenhagen: WHO Regional Office for Europe http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

[46] World Health Organization (2009) WHO guidelines for indoor air quality: dampness and mould. Copenhagen: WHO Regional Office for Europe http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2009/damp-and-mould-health-risks,-prevention-and-remedial-actions2/who-guidelines-for-indoor-air-quality-dampness-and-mould

[47] 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 (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. London: The Stationery Office ISBN 978-0-10-171692-5.

Table 6.1 presents the WHO indoor air quality guidelines and UK ambient air quality objectives. In addition to these there are HSE guidelines for wood and dust particles and fumes that apply to wood, metalwork and soldering activities. Workplace levels also apply to ash handling on biofuel boiler plant.

Approved Document F gives performance levels for indoor air quality in office-type accommodation. These performance levels are updated as appropriate in Table 6.1 to align with the World Health Organization (WHO, 2010) indoor air quality guidelines and should be used for schools.

For buildings with no other humidity requirements than human occupancy (e.g. offices, schools and residential buildings), humidification or dehumidification is usually not needed. Short-term exposure to very low or high values can be accepted.

AD F also sets a Total Volatile Organic Compounds (TVOC) limit of 300 $\mu g/m^3$ (8 hr).

EH40 Workplace exposure levels exist for many more chemicals than the other standards and represent the highest acceptable limits for exposure of workers. Pollutant levels in Science, Design and Technology and Art should always be kept below the levels given in EH40.

Indoor concentrations of naturally occurring radon are identified by measurement. Workplaces with high radon levels fall within the scope of the Ionising Radiations Regulations 1999.

Table 6.1 WHO Indoor air quality guidelines and UK ambient air quality objectives

Pollutants	WHO Indoor Air Quality Guidelines(2010)[48]	UK Air Quality Objectives (DEFRA, 2007)[49]
CO (mg/m3)	100 (15 min)	
	60 (30 min)	
	30 (1 hr)	
	10 (8 hr)	10 (8 hr)
	7 (24 hr)	
NO_2 (µg/m^3)	200 (1hr)	200 (1 hr)
	40 (1yr)	40 (1yr)
SO_2 (µg/m^3)		266 (15min)
		350 (1 hr)
		125 (24 hr) not to be exceeded more than 3 times a year
PM_{10} (µg/m^3)		50 (24 hr)
		40 (1 yr) – UK
		18 (1 yr) – Scotland
$PM_{2.5}$ (µg/m^3)		25 (1 yr) – UK
		12 (1 yr) – Scotland
Ozone (µg/m^3)		100 (8 hr)
Radon (Bq/m^3)	No safe level	From Ionising Radiations Regulations 1999 not Defra AQO: 400 (approximately equal to annual average of 270)
	Reference level: 100	
	No more than: 300	
Benzene (µg/m^3)	No safe level	
		5 (1 yr) - England and Wales
		3.25 (running annual mean) - Scotland, N.Ireland
Trichloroethylene (µg/m^3)	No safe level	
Tetrachloroethylene	250 (1yr)	

[48] WHO Indoor Air Quality Guidelines, 2010, http://www.who.int/indoorair/publications/9789289002134/en/

[49] DEFRA (2007) The UK Air Quality Strategy for England, Scotland, Wales and N. Ireland https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69336/pb12654-air-quality-strategy-vol1-070712.pdf

Pollutants	WHO Indoor Air Quality Guidelines(2010)[48]	UK Air Quality Objectives (DEFRA, 2007)[49]
(μg/m^3)		
Formaldehyde (μg/m^3)	100 (30 min)	
Napthalene (μg/m^3)	10 (1yr)	
PAHs (ng.m^{-3} B[a]P)	No safe level	0.25 (annual average)
1,3-butadiene (μg/m^3)		2.25 (running annual mean)
Lead (μg/m^3)		0.25 (1yr)

Notes:
1y: annual mean / 24h: 24 hour mean / 1h: 1 hour mean / 30 min: 30 minute mean
Conversion to ppm at 25 ºC and 1 atmosphere: X ppm = (Y mg/m^3)(24.45)/(molecular weight)

6.2 Indoor air pollutants

In line with the above guidelines, the SINPHONIE project proposed and used the pollutants that are presented in Table 6.2, as indicators for IAQ.

Table 6.2 SINPHONIE indicators for IAQ monitoring in European schools (Kephalopoulos et al., 2014)

Physical and chemical pollutants	Micro-biological pollutants
Benzene Trichloroethylene Tetrachloroethylene Formaldehyde Naphthalene Benzo(a)pyrene a-pinene d-limonene PM2.5 PM10 NO2 Ozone CO Radon	Endotoxin Specific fungal and bacterial groups • *Penicillium/Aspergillus* group • *Cladosporium herbarum* • *Aspergillus versicolor*, • *Alternaria alternate* • *Trichoderma viride* • *Streptomyces* spp. • *Mycobacterium* spp. Allergens House-dust mites Horse, cat and dog allergens

The sources and health effects of the pollutants in Table 6.2 are discussed in the SINPHONIE guidelines for schools and are presented in Annex B.
In addition to Table 6.2 and Annex B. Indoor air pollutants, sources and health effects, it should be noted that:

(CO_2) – is an indicator of indoor air quality. Exhaled air is usually the principal source of CO_2 in schools. CO_2 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.

CO_2 levels from combustion may be particularly high in food cooking areas,science labs and technology areas when gas cookers or 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. Historically the level of outdoor air provided to a classroom was specified to avoid significant odour as perceived by persons entering the room. Occupants already in the room will not be aware of odour, as the olfactory sense rapidly adjusts to an odour. Odours can therefore build up to unpleasant levels and a sufficient outdoor air supply is needed to dilute and remove them.

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.

Volatile organic compounds (VOCs) – See Annex B. Indoor air pollutants, sources and health effects for information on the VOCs in Table 6.2. There is a wide range of organic compounds ranging from very volatile compounds (VVOCs) such as formaldehyde to semi-volatile compounds (SVOCs) such as phthalate plasticisers.

VOCs can present a risk to the health and comfort of occupants if concentrations in air exceed those known to cause adverse effects. Some are known to be toxic and can adversely affect children particularly those in vulnerable groups (for example, those that suffer asthma and allergies). At the levels found in school buildings their most likely health effect is short-term irritation of the eyes, nose, skin and respiratory tract. Odour generated by VOCs can also be a concern to the occupants. VOCs can be released from a wide range of construction, furnishing and consumer products used indoors (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; percholoethylene; methylene chloride; toluene.

Combustion gases – Burning of fuel for heating, hot water and for cooking releases potentially harmful gases such as carbon monoxide and nitrogen dioxide as well as particulates (including PM_{10} and $PM_{2.5}$ size fractions) and organic compounds. Hence the need for appropriate venting of fumes and regular maintenance of combustion appliances and venting systems.

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 materials are disturbed or become damaged, asbestos fibres may be released into the air and present a risk if inhaled. Some damaged ACMs can be made safe by repairing them and sealing or enclosing them to prevent further damage. Where ACMs cannot be easily repaired and protected, they 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, HSE guidance[50] and the DfE guidance on asbestos management for schools[51].

Radon –

Dust and Fume - Workplace exposure limits are published by HSE for wood dust and other pollutants arising from the teaching of Design and Technology and Construction.

Water treatment chemicals – Swimming pools have two causes of pollutants. The first is the water treatment chemicals themselves and the second is the breakdown products resulting from the water treatment[52].

6.3 Sources of indoor pollutants

Pollutants in the indoor environment may originate from outdoor sources. The description and main outdoor sources for each pollutant, as well as their potential effects on health/environment are discussed in the UK AQ Strategy (Volume 1). Pollutants emitted indoors originate from occupants and their activities, and also

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[50] Health and Safety Executive (2000), Asbestos - An Important Message For Schools, http://www.hse.gov.uk/services/education/asbestos-faqs.htm

[51] https://www.gov.uk/government/publications/asbestos-management-in-schools--2

[52] See references for guidance on the control of these pollutants.

from the building itself and from cleaning materials and furnishings. The typical sources of indoor air pollutants are presented in Table 6.3.

Table 6.3 Typical sources of indoor air pollutants in school buildings

<table>
<tr><th>Outdoor sources</th><th>Building equipment, components & furnishings</th><th>Other potential indoor sources</th></tr>
<tr><td rowspan="2">Outdoor air pollution
• Pollen, dust, mould spores
• Industrial emissions
• Vehicle emissions
• Agriculture and farms
• Outdoor machinery emissions</td><td>HVAC equipment
• Mould growth in drip pans, ductwork, coils and humidifiers
• Improper venting of combustion products
• Dust or debris in plenums and ducts</td><td rowspan="4">• Science laboratory substances
• Vocational art substances
• Design and technology materials
• Food preparation areas
• Cleaning materials/air fresheners
• Emissions from rubbish
• Pesticides and weedkillers
• Odours, PM (particulate matter) and VOCs from paint, mastics, adhesives, varnishes
• Occupants with infectious diseases
• Dry-erase markers and similar pens
• Insects and other pests
• Personal care products
• Stored petrol and lawn and garden equipment
• Combustion appliances for heating and cooking
• Cleaners stores
• Chemical stores
• Battery rooms.</td></tr>
<tr><td>Other equipment
• Emissions from office equipment (volatile organic compounds, ozone)
• Emissions from shop, lab and cleaning equipment</td></tr>
<tr><td>Nearby sources
• Loading bays
• Odours from rubbish bins
• Unsanitary debris or building exhausts near outdoor air intakes</td><td>Components
• Mould growth on or in soiled or water damaged materials
• Dry drain traps that allow the passage of sewer gas
• Materials containing VOCs (volatile organic compounds), inorganic compounds or damaged asbestos
• Materials that produce particles(dust) or fibres</td></tr>
<tr><td>Underground sources
• Radon
• Pesticides
• Leakage from underground storage tanks</td><td>Furnishings
• Emissions from new furnishings and floorings
• Mould growth on or in soiled or water damaged furnishings</td></tr>
</table>

6.4 Minimising sources

6.4.1 Indoor source control

Potentially harmful emissions can be reduced by avoiding or eliminating sources of pollutants; for example, careful selection of materials and products can minimise VOC emissions. Reduction of VOCs is one of the most inexpensive of the BREEAM[53] credits to achieve.

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 contaminated by things other than from normal human activity (CO_2, moisture from exhalation, etc.) such as from kitchens and fume cupboards, should be prevented. See section 4.4.1 for guidance on location of exhaust outlets and section 5.2.5 on Fume Cupboard Exhausts.

Extract outlets should be designed to avoid risk of unintentional recirculation into a supply inlet or natural ventilation opening. Extract systems or transfer arrangements should be designed to ensure there is a minimum possibility of back draughts from one area to another.

ASHRAE 62-2 gives air classifications that state where air can be drawn from. 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.

Good practice is to use the smallest possible quantities of chemicals in experiments and other activities that involve hazardous chemicals. See CLEAPSS guidance for science[54]. If this is done pollutant levels will be low.

The removal of pollution sources is a much more effective way to control indoor air quality than diluting the pollutant concentrations by ventilation. This may allow ventilation rates to be lowered, thus providing a potential saving in energy use.

The SINPHONIE guidelines provide an overview of regulatory and voluntary labelling schemes for low VOC (Volatile organic compound) emitting products in the EU (presented in

[53] See BREEAM Technical Manuals for non-Domestic Buildings, available from http://www.breeam.com/technical-standards

[54] www.cleapss.org.uk

Table 6.4) as well as a guide to eliminating chemical emissions from building materials and products (Annex C. Guidance on construction products and materials in school buildings There are currently no equivalent English or Welsh labelling schemes. However, a harmonised system of labelling of products according to performance with respect to emission to indoor air is being developed under the Construction Products Regulation No. 305/2011 (CPR, 2011[55]). When available products used during the construction or refurbishment of schools should be selected with harmonised labelling demonstrating a low adverse impact on indoor air. In the absence of such a harmonised scheme as far as possible products should be selected that have been shown to have good emission performance according to a scheme shown in

[55] Construction Products Regulation (CPR, 2011) Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

Table 6.4.

Some construction products such as glass, stone and ceramics have low emissions because of their composition. The EU directive 2004/42/CE21 gives some indication of emissions due to the VOC content of paints. Low solvent adhesives may be tested to demonstrate absence of carcinogenic and sensitising substances (BS EN 13999 Part 1:2006). Construction and furnishing products containing formaldehyde (including formaldehyde containing resins) such as wood based boards should meet emission class E1 or equivalent (BS EN 13986:2004, BS EN 14080:2005, BS EN 14342:2013, BS EN 14041:2006, BS EN 13964:2004).

Table 6.4 Building materials, product labels on chemical emissions in EU

Building materials and products labels and guidance on chemical emissions in EU
• European Ecolabel (e.g. textile-covered flooring, wooden flooring, mattresses, indoor and outdoor paints and varnishes: Europe), http://ec.europa.eu/environment/ecolabel/
• EMICODE® (adhesives, sealants, parquet varnishes and other construction products: Germany/Europe), http://www.emicode.com/index.php?id=1&L=1
• GUT (carpets: Germany/Europe), http://pro-dis.info/86.html?&L=0
• Blue Angel (Germany), http://www.blauer-engel.de/en/index.php
• Nordic Swan (Scandinavia), http://www.svanen.se/en/Nordic-Ecolabel/
• Umweltzeichen (Austria), http://www.umweltzeichen.at/cms/home233/content.html
• AgBB (Specifications for construction products: Germany), http://www.umweltbundesamt.de/themen/gesundheit/kommissionenarbeitsgruppen/ausschuss-zur-gesundheitlichen-bewertung-von
• M1 (construction products: Finland), www.rakennustieto.fi/index/english/emissionclassificationofbuildingmaterials.html
• ANSES (formerly AFSSET) (construction products: France), http://www.anses.fr/fr/upload/bibliotheque/892980998778406505212938602998/COV_Avis_signe_2009_10.pdf
• CertiPUR (PU foam for furniture industry: Europe), http://www.europur.com/index.php?page=certipur
• Ü mark (specifications in relation to CE marking: Germany), https://www.dibt.de/index_eng.html
• Danish Indoor Climate Label, http://www.teknologisk.dk/ydelser/dansk-indeklimamaerkning/dim-omfatter/253,2
• Swedish 'byggvarudeklaration' (construction products: Sweden, http://www.byggvarubedomningen.se/sa/node.asp?node=455
• Natureplus (construction products: Germany/Europe, http://www.natureplus.org/

Further information about control of emissions from construction products is available in BRE Digest 464 [56], and information on source control to minimise dust mite allergens is available in BRE Report BR 417 [57].

6.5 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

[56] BRE Digest 464: VOC Emissions from Building Products Parts 1 and 2; IP 12/03 VOC Emissions from Flooring Adhesives.
[57] Raw G. J., Aizlewood C. E. and Hamilton R. M. (2001) Building Regulation, Health and Safety. BRE Report 417. BRE bookshop: www.brebookshop.com/

need to be considered include those covered by the UK National Air Quality Strategy (NAQS) (DETR, 2007)[58]. These are presented in Table 6.1. The description and main UK sources for each pollutant, as well as their potential effects on health/environment are discussed in the UK AQ Strategy (Volume 1).

London and major UK cities now require measures to tackle the problem of exposure of staff and students to frequent high air pollution while working and studying inside school buildings.

There is a problem of elevated air pollution levels close to some schools that requires the location of air intakes in unpolluted zones or the use of air filtration units and effective air filtration in school ventilation systems.

Air filtration is the most effective solution currently available to remove health damaging airborne pollutants and maintain clean indoor air for school buildings located in these air pollution hotspots. Designers of ventilation systems for schools in areas of high pollution may therefore need to incorporate air filtration in such locations.

6.5.1 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).

[58] 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 (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. London: The Stationery Office ISBN 978-0-10-171692-5.

Further information can be found in Kukadia and Hall (2004)[59].

The SINPHONIE guidelines[60] recommend that better control over the quality of the outdoor air that enters the school indoor environment can be achieved by choosing "pollution-free" zones for new schools, by promoting compliance with the air quality standards for ambient air near existing schools, and, consequently, by imposing stricter measures to improve traffic conditions in the vicinity of schools (e.g. within a radius of 1 km). In London, high NO_2 (nitrogen dioxide) concentrations have been measured at the kerbside and roadside monitoring stations[61]. The NO_2 NAQS objective was exceeded alongside almost every road where measurements took place. The greatest concentrations were over three times the NAQS objective. In the case of PM_{10}, there were only a few exceedances.

Many schools are located in polluted urban areas where pollutant levels exceed the maximum guideline levels in Table 6.1. It is therefore often necessary to consider the best means to ameliorate the effects of high levels of outside pollution as part of the design of the ventilation of school buildings.

The draft EN 13779[62] suggests the following starting points for Outdoor air classification (ODA 1 to 3) and Supply air classification (SUP 1 to 3):

ODA1 applies where the WHO (2005) guidelines and any National air quality standards or Regulations are fulfilled.

ODA2 applies where pollutant concentrations exceed the WHO guidelines or any National air quality standards or Regulations for outdoor air by a factor of up to 1.5.

ODA3 applies where pollutant concentrations exceed the WHO guidelines or any National air quality standards or Regulations for outdoor air by a factor greater than 1.5.

SUP 1 applies where the supply air fulfils the WHO (2005) guidelines limit values and any National air quality standards limit values or Regulations with a factor x0.25

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[59] 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
[60] Kephalopoulos S., Csobod, E, Bruinen de Bruin Y, De Oliveira Fernandes E. Guidelines for healthy environments within European schools Co-published by the European Commission's Directorates General for Health and Consumers and Joint Research Centre, Luxembourg, 2014. ISBN 978-92-79-39151-4
[61] Fuller G, Mittal L. Air Quality in London – briefing note to GLA Environment and Health Committee July 2012, King's College London.
[62] BS EN 13779 standard is currently under revision (See prEN 16798-3 and prCEN/TR 16981-4).

SUP 2 applies where the supply air fulfils the WHO (2005) guidelines limit values and any National air quality standards limit values or Regulations with a factor x0.5

SUP 3 applies where the supply air fulfils the WHO (2005) guidelines limit values and any National air quality standards limit values or Regulations with a factor x0.75

SUP 4 applies where the supply air fulfils the WHO (2005) guidelines limit values and any National air quality standards limit values or Regulations

Note: ODA1 is the least polluted outdoor air and SUP1 is the highest quality of supply air.

6.5.2 Filtration

Filtration provides a means of cleaning the intake air. Filtration also ensures that mechanical ventilation systems continue to operate at their optimum level - protecting fans and energy recovery devices. It is standard practice to fit filters to mechanical ventilation systems. Recommendationss for specification of filters are given in CIBSE Guide B and BS EN 13779. This Euronorm is referenced in the UK National Calculation Method for Part L calculations and in the Euronorms to be used in energy calculations for room based ventilation systems.

There are also other methods of cleaning air, such as air cleaners; electrostatic filters; culverts where pollutants drop out, and surfaces, absorbent materials and plants that absorb pollutants.

Ventilation system air-intake filters are usually used for particle removal. Activated carbon filters are required if it is necessary to remove gaseous pollutants. As these are costly and difficult to maintain it is preferable to avoid the need for removal of gaseous pollutants from outside air if possible by effective positioning of intakes.

It is important that filters are replaced regularly to maintain good air quality. If filters are not maintained, they can become saturated leading to increased pollutant levels, potential microbial growth and odours. Microbial growth can also result from stagnant water in drain pans or from uncontrolled moisture inside air ducts and cooling coils.

Where filters are fitted a means should be provided to warn building operators that filters are dirty and need changing: This can be by means of:

1. a filter dirty signal recorded on the local ventilation controller and on a BMS (building management system) where provided; or
2. by runtime alarm and shut-off

This is in addition to a manometer fitted to the AHU (air handling unit).

Table 6.5 Recommended minimum filter classes per filter section (definition of filter classes according to EN 779)

Outside air quality				
	SUP 1	SUP 2	SUP 3	SUP 4
ODA 1	M5 + F7	F7	F7	F7
ODA 2	F7 + F7	M5 + F7	F7	F7
ODA 3	F7 + F9	F7 + F7	M5 + F7	F7

Where Table 6.5 shows M5 + F7 filters this is a two stage particle filter system with M5 placed before the F7 filter.

Table 6.5 also advises on minimum final (or single) stage filtration class eg. F7 or F9 but also in some cases advises on the pre-filter class M5 or F7. The F7 pre-filter should be a high capacity bag filter. It can be used in the pre-filter position (or as a single stage) because it has the capacity to handle the coarse particle size range.

Table 6.5 air filters are selected to clean polluted air sufficiently so that it can be inhaled by school building occupants without risk to health. Where the air is not polluted and cleaning the air for people to breathe in the building is not an issue then preservation of air moving plant efficiency becomes the overriding issue and the recommended filter classification of G4 or G5 given in CIBSE Guide A Table 1.5 for schools can be used.

The G, M and F filter ratings come from the European EN 779:2012 classification system.

G stands for Coarse (Grob in German) it has been given the alternative meaning of G for Gravimetric which is the type of testing that applies to this class of filter.

G3 or G4 class filters only have an efficiency of about 3% to 5% to remove fine particles such as those found in traffic emissions. They are not therefore effective in protecting people against exposure to traffic sourced air pollution.

F denotes Fine class filter for filtering out a high level of fine particles making it suitable for final stage filtration in an air system supplying air to people in (school) buildings.

M stands for medium class filters, these filters were F class before 2012 but are now regarded as lacking the required fine particle removal efficiency to be used in final stage filtration in an air system supplying air to people in (school) buildings. They will not make the supply air into buildings clean enough to breathe, without risk to health.

This is especially the case in the range of airborne particles one micron diameter and below in size.

G4 or G5 filters can be used as coarse filters to protect cross flow heat exchangers as recommended by CIBSE Guide B Table 1-5.. However in this case, according to Table 6.5, it is far more effective to place an M5 or F7 pre-filter instead of the less efficient G4, or G5 filter upstream of the heat exchanger or coil, thus keeping it cleaner and protecting its heat transfer efficiency, while placing a final stage filter at the end of the AHU just before the supply air duct.

Many outdoor air guidelines refer to PM_{10} (particulate matter with an aerodynamic diameter up to 10 µm) but there is growing consensus that, for the purpose of health protection, greater emphasis should be placed on smaller particles and use as a criteria particle concentration up to 2.5 µm ($PM_{2.5}$) as a limit value.

The EU Healthvent study published in 2013 advises $PM_{2.5}$ minimum reduction by 50%. This is achieved by F7 class air filters.

For sites subject to traffic pollution BS EN 13779:2007 recommends an air filtration efficiency of 80% (F9) for effective fine particle removal and also recommends gas filtration using a carbon filter for removal of NO_2.

6.5.5 Biomass boiler flues

The World Health Organization has no lower acceptable safety limit for the key constituents of biomass combustion fumes. Storage of biomass also poses risks to health from carbon monoxide and methane build up from decay of biomass and from dust[63]. The smell of storing biomass and the safe handling on site of biomass and ash should be considered. See CIBSE AM15 Biomass Heating Application Manual, 2014.

Advice on Chimney height design is given in IGEM UP/10 and in guidance on the Clean Air Act. Detailed design information is also given in LAQM.TG.(09)[64]. Chimney height approval under the Clean Air Act is a separate consenting process from planning consent.

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[63] HSE bulletin OPSD3-2012 'Risk of carbon monoxide release during storage of wood pellets, http://www.hse.gov.uk/safetybulletins/co-wood-pellets.htm

[64] Local air quality management: Technical guidance LAQM.TG(09). Department for Environment, Food & Rural Affairs.

6.5.6 Building airtightness and thermal bridging

Low air infiltration rates 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 (AD L) of the Building Regulations (2013 in England and 2014 in Wales). The importance of air leakage for energy performance is reflected in the fact that air leakage in the Notional buildings is much less than the maximum allowable.

AD L specifies minimum performance requirements in terms of air permeability. Air permeability is defined as the air leakage in m^3h^{-1} per metre square ($m^3h^{-1}m^{-2}$) of building envelope area, which includes the ground-supported floor area, at a reference pressure of 50 Pa. Details on achieving and verifying performance are given in ATTMA publications[65].

External louvre and damper construction should consider thermal bridging and line of the thermal envelope should be shown on construction drawings. Thermal performance of should be determined.

Manufacturers should be required to test the air leakage and thermal performance of their louvre damper assemblies as described in Section 4.10.1.

As modern buildings are very airtight it is essential to provide tempered make up air for processes such as fume and dust extraction as part of the ventilation design.

[65] *ATTMA Technical Standard L2, "Measuring air permeabiity of building envelopes (Non-dwelliings)", 2010*

7. Thermal comfort

This Section of BB101 describes the thermal comfort criteria for the different spaces and activities in a school. Section 7 uses the comfort category descriptions from BS EN 15251, see Table 7.1. Note that a space may have different comfort categories for different thermal comfort criteria. For example a sports hall has a category IV for cold draughts (see Table 7.5) but a category III for the summertime overheating risk assessment (see Table 7.9).

Standards for all aspects of thermal comfort are set out in BS EN ISO 15251[66]. These are also the basis of the guidance in CIBSE Guide A, 2015. Thermal perception is influenced by many factors and is generally expressed in terms of whether people feel neither too hot nor too cold.

The standards for thermal comfort in BS EN 15251 during the heating season or when spaces are tempered, i.e, heated or cooled, are based on results of climate chamber studies. The standards were derived from analyses of the perception of a large sample of adults to their surrounding environment.

The resulting methodology is documented in CR 1752, ISO 7730 and BS EN ISO 10551 which relate the factors contributing to thermal comfort to predicted mean vote (PMV) and percentage people dissatisfied (PPD) indices.

These PMV and PPD indices predict the thermal comfort of people working in a given conditioned reasonably steady state environment, and have become the most widely used indices for conditioned buildings, having been adopted as a British and European, and International standard, especially where mechanical cooling is provided.

The PMV predicts the mean response of people within the same environment, and the PPD gives a quantitative measure of how many of these people would be dissatisfied with the comfort of the environment.

For comfort conditions for people with special requirements such as those with physical disabilities, ISO 7730 refers to ISO/TR 14415:2005, 4.2. Where pupils have special educational needs that affect their temperature response or for very young pupils an assessment of their particular needs will be required which may mean that higher categories of comfort criteria may be needed in particular areas of a school or across the whole school.

[66] This document is based on the 2014 draft revision of EN 15251. See References.

The main factors that influence thermal comfort are those which directly affect heat gain and loss and can be grouped into two categories: "environmental factors" which are conditions of the thermal environment, and "personal factors" which are characteristics of the occupants. The environmental factors are; air temperature, mean radiant temperature, air speed, location and direction of air movement, turbulence intensity, and relative humidity. There are various personal physiological and psychological factors as well as the personal factors of; clothing insulation level and metabolic rate (which is a function of age, body shape and activity).

Specialist advice from an environmental engineer should be sought regarding the design of the building fabric as well as the heating and ventilation systems to take the thermal comfort issues into consideration.

7.1 Thermal comfort criteria

BS EN 15251 thermal comfort criteria are based on the following categories of building:

Table 7.1 Categories of space/activity

Category	Explanation
I Equivalent to Category A of EN ISO 7730: 2005	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility
II Equivalent to Category B of EN ISO 7730: 2005	Normal expectation
III Equivalent to Category C of EN ISO 7730: 2005	An acceptable moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

BS EN 15251 gives comfort criteria for both mechanically cooled buildings and for free running buildings. A free running building is defined as a building, with either natural or mechanical ventilation, which is not actively heated or cooled.

The thermal comfort criteria for schools in Sections 7.2 to 7.6 are based on: the adaptive thermal comfort standards for free running buildings outside the heating season; PD CR 1752:1999; ISO 7730; and BS EN 15251 with local interpretation for children and schools and for the UK, as described in CIBSE TM 52; and CIBSE Guide A.

For refurbished buildings, the minimum standard is Category IV where Category III cannot be met for reasons of practicality and due to the extent of refurbishment. However, after refurbishment the criteria should not be worse than before refurbishment in any aspect affecting thermal comfort.

7.2 Operative temperature range

The operative temperature (which has replaced dry resultant temperature in CIBSE texts) combines the effects of the air temperature and the mean radiant temperature[67] within a limited range of air velocity and humidity.

Using the CIBSE equation for simple model heat losses, as detailed in CIBSE Guide A Section 5.8.1; rooms can be examined to determine the effect of emitter type on all key parameters that make up the thermal environment when heating the space.

The designer should ensure that there are sufficient temperature control mechanisms provided to enable the occupants or the teacher to adjust the internal temperature and influence the environment and maintain a satisfactory level of comfort throughout the year. Recommended operative temperatures in the heating season are listed in Table 7.2. Temperature, ventilation and lighting controls in schools should be classroom based and simple to operate.

[67] Mean radiant temperature is as defined in Section 1.2.2 of CIBSE Guide A (2015 edition). Further informaton is given at http://www.healthyheating.com/Definitions/Mean%20Radiant.htm

Table 7.2 Recommended operative temperatures during the heating season measured at 1.4m from the floor in the centre of the room

	Normal maintained operative temperature - ^{0}C	Maximum operative temperature during the heating season at maximum occupancy - ^{0}C
Stores	5°C	N/A
Areas where there is a higher than normal level of physical activity (such as sports halls) and sleeping accommodation	17°C	23°C
Toilets, circulation spaces and store rooms that are normally occupied	17°C	24°C
Kitchen preparation areas	20°C	N/A
Spaces with normal level of activity, teaching, study, exams, admin and staff areas, prep rooms, including practical spaces, and computer suites	20°C	25°C
Spaces with less than normal level of activity or clothing, including sick, isolation rooms, changing rooms and gymnasia and dance and movement studios	21°C	26°C
Special schools and resourced provision, where needs of pupils tend to be complex and varied, including pupils with physical difficulties or profound and multiple learning difficulties.	23°C	25°C
Where pupils or adults may be wet and partially clothed for a significant length of time, such as swimming pools;	23°C in changing rooms and no more than $1^{0}C$ above or below that of the water temperature in pool halls subject to a maximum of $30^{0}C$	28°C in changing rooms and no more than $1^{0}C$ above that of the water temperature subject to a maximum of $30^{0}C$ in pool halls
Where young children or those with SEN (Special education needs) or physical disabilities may be wet or partially clothed for a significant length of time Rapidity of air movement can lead to chilling by evaporation and to compensate, a higher design temperature may be required.	25°C The air speed in these environments should be as low as possible and not exceed 0.15 m/s at 25°C	30°C

7.3 Local thermal discomfort caused by draughts

In order to reduce the problem of draughts, which frequently prevents windows from being opened in densely occupied classroom spaces with low-level air inlets, EFA has developed the following guidelines for local thermal comfort.

The design of ventilation and its control should provide mixing of ventilation air with room air to avoid cold draughts in the occupied zone.

Table 7.3 Comfort categories for cold draughts

Space/Activity	Minimum recommended comfort category for draught
Stores, corridors and circulation spaces that are not normally occupied spaces,	N/A
Areas where there is a higher than normal level of physical activity (such as sports halls) and sleeping accommodation	Category IV. Low air speeds required for Badminton competitions may necessitate ventilation systems being switched off
Toilets, circulation spaces and store rooms that are normally occupied	Category IV
Kitchen preparation areas	N/A
Spaces with normal level of activity, teaching, study, exams, admin and staff areas, prep rooms, including practical spaces, and computer suites	Category II or III or Category IV where there is local manual control over the ventilation rate eg manually opened windows or room ventilation with on/off and variable speed control
Spaces with less than normal level of activity or clothing, including sick, isolation rooms, changing rooms and gymnasia and dance and movement studios	Category II or III
Special schools and resourced provision, where needs of pupils tend to be complex and varied, including pupils with physical difficulties or profound and multiple learning difficulties.	Category I or II
Where pupils or adults may be wet and partially clothed for a significant length of time, such as swimming pools;	Category II
Where young children or those with SEN (Special education needs) or physical disabilities may be wet or partially clothed for a significant length of time Rapidity of air movement can lead to chilling by evaporation and to compensate, a higher design temperature may be required.	Category I

Category IV should only be used in classrooms and other teaching spaces where there is local control over the room ventilation with variable speed control with override control by the teacher. The air quality criteria regarding CO_2 levels must still be met.

7.3.1 Natural ventilation systems

The decision of whether or not natural ventilation is suitable should be based on the temperature difference on a cold still day during mid-season when the heating system is switched off. This assessment does not need to consider the velocity of the supply air plume but only its temperature. However, higher air speeds for summer daytime purge cooling of classrooms can be a nuisance if they blow papers off desks. The Line Plume Calculator should be used to assess the temperature of the incoming plume of air from high level openings when it reaches the occupied zone.

When the outside air temperature is 5ºC, and the heat emitters are switched off the minimum air temperature of air delivered to the occupied zone at seated head height shall be not more than 5°C below the normal maintained air temperature given in Table 7.2. Seated head height should be taken as 1.1m above floor level for primary and 1.4m above floor level for secondary school classrooms.

For Category I spaces the temperature difference must be less than 3ºC whenever the natural ventilation system is in use.

The line plume calculator[68] can be used to estimate the temperature of air at the occupied zone or alternatively measurements can be made in test rooms or CFD models can be used.

7.3.2 Forced draught systems

In a mechanical system where the driving force for the supply air is a fan, Table 7.4 gives values for the maximum temperature difference between the operative temperature of the room and the temperature of the supply air jet or plume and the maximum local air speed of the jet or plume for the different comfort categories for schools. This is based on the comfort criteria in BS EN 15251 for mechanical ventilation systems.

[68] The Line Plume Calculator from http://www.breathingbuildings.com/design-tool/cold-draught-calculator

Table 7.4 Recommended draught criteria for mechanical ventilation systems to provide thermal comfort

Category of space/activity	Draught criteria to provide thermal comfort			
	Winter		Summer and mid-season	
	∆T (Min maintained operative temp - plume local air temp)	Maximum air velocity (m/s)	∆T ($T_{room, operative}$ - plume local air temp) When T_{room} ≤25°C or T_{comf}	Maximum air velocity (m/s)
I	1.5	0.15	1.5	0.15
II	2	0.2	2	0.2
III	3	0.25	3	0.25
IV	4	0.3	5	0.3

Table 7.4 assumes an activity level of 1.2 met, a clo value of 1.1 in winter 0.9 in mid-season and 0.7 in summer, and a minimum maintained operative temperature as in Table 3.10 in winter and mid-season and 23°C in summer.

The values in Table 7.4 apply to the supply air plume which delivers air to the occupied zone. The occupied zone should be taken as from 0.6m to 1.4m above floor level.

Higher speeds and larger temperature differences are permitted in winter for boost ventilation under the control of the teacher e.g. in Science or Food Technology.

For summertime cooling purposes, higher maximum air speeds are allowed and often preferable (draught becomes pleasurable breeze), but only under the condition that the teacher or the occupants have direct control over the openings or fans.

CFD (Computational fluid dynamics) modelling is not expected to estimate room air speeds. Manual calculations based on manufacturers information can be used to predict the speeds and they can be measured with an anemometer. Grille manufacturers supply the necessary tables to predict velocity at the occupied zone. Temperature will be based on the temperature of the jet and the appropriate entrainment coefficients. If required to measure air velocity, it should be measured with an omni-directional anemometer with a 0.2s time constant.

The criteria for maximum local air speed and minimum local temperature of the supply air plume can be related mathematically by the method given in BS EN ISO 7730 to obtain a Predicted Mean Vote (PMV) that is related to PPD. This requires the clo value of the clothing and the metabolic rate of the occupants to be known. By using this formula, equivalent conditions to those given in Table 7.4 can be obtained that give the same or a better PPD, eg, a slightly higher air speed can be used with a slightly higher supply air temperature.

7.4 Radiant temperature difference

Being surrounded by surfaces that have large temperature differences is a frequent cause of discomfort, even when the air temperature is within the acceptable limits. These conditions can be caused by cold or hot windows, walls or ceilings, direct sunlight, or improperly designed heating systems.

Varying surface temperature influences the Radiant Temperature Asymmetry (RTA), and in general, people are more sensitive to a warm ceiling than hot or cold vertical surfaces. For a warm ceiling, Radiant Temperature Asymmetry is defined in ISO 7730 as the difference between the Plane Radiant Temperatures measured in the upwards and downwards directions ($\Delta T_{pr,, upwards}$). It is an indication of the effect on body core temperature of the asymmetry between floor and ceiling.

For rooms incorporating overhead radiant panels the designer should undertake calculations to determine the RTA within each space. In calculating the RTA, $\Delta T_{pr,, upwards}$ can be assessed directly below a radiant panel or an array of panels using the formulae in BS 7726.

For a seated person, the difference in plane radiant temperature between the upper and lower parts of the space should be taken with respect to a small horizontal plane 0.6m above floor level in accordance with CIBSE Guide A Section 1.6.6.4 (2015 Edition). For a standing person a small horizontal plane 1.1m above floor level should be considered.

It is recommended that the RTA due to the presence of radiant panels overhead should not exceed 7K.

This is particularly important when there is a sedentary occupation such as people sitting at a desk. Where there are vulnerable pupils, e.g., those with low mobility or difficulty in thermoregulation, the RTA should be reduced to 5K.

Indicative minimum panel installation heights for a seated person are given below for a RTA of 7K and 5K. These tables are based on the seated person being positioned directly below the centre of a single overhead radiant panel in a typical classroom configuration.

Table 7.5: Radiant Temperature Asymmetry, RTA = 7K

Flow/Return Temperature (°C)	Assumed Emitter Temperature (°C)	Panel width (mm)				
		300	600	750	900	1200
		Minimum panel height above finished floor level (m)				
50/30	40	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4
60/40	50	< 2.4	< 2.4	< 2.4	2.55	3.05
70/40	55	< 2.4	< 2.4	2.55	2.85	3.4
70/50	60	< 2.4	2.45	2.85	3.2	3.75
80/60	70	< 2.4	2.95	3.35	3.75	4.45
82/71	76.5	< 2.4	3.25	3.7	4.1	4.85

Table 7.6: Radiant Temperature Asymmetry, RTA = 5K

Flow/Return Temperature (°C)	Assumed Emitter Temperature (°C)	Panel width (mm)				
		300	600	750	900	1200
		Minimum panel height above finished floor level (m)				
50/30	40	< 2.4	< 2.4	< 2.4	< 2.4	2.85
60/40	50	< 2.4	2.5	2.85	3.2	3.8
70/40	55	< 2.4	2.8	3.2	3.55	4.2
70/50	60	< 2.4	3.1	3.55	3.95	4.65
80/60	70	< 2.4	3.65	4.15	4.6	5.4
82/71	76.5	2.6	4	4.55	5	5.85

The designer will be required to undertake the design considering the mean water temperature, size of radiant panels and the available mounting height. Mounting too low can result in occupants complaining of excessive temperatures above their head and if mounted too high, occupants may not feel the full heating benefit.

The designer should consider the arrangement of radiant panels within a space once the mounting height is established, to ensure sufficient separation between the units is achieved to provide an even spread of heat throughout the space whilst preventing a crossover of the radiant flow of heat between panels resulting in zones of intense heat.

Locating radiant panels directly above teaching walls or other areas where a teacher or other occupant would be likely to be standing for prolonged periods of time should also be avoided unless RTA calculations can demonstrate that the installation is suitable and would not result in excess temperature differences.

In many instances, the preferred layout of radiant panels clashes with the lighting layout, and for aesthetics, the radiant panels are often offset as part of the services coordination. The designer on detecting such a clash should assess the impact on RTA resulting from offsetting the radiant panels. The option of integrating luminaires and acoustic absorbers within radiant panels should be considered.

Hot water radiators[69] have a lower radiant component than radiant panels i.e. 10% to 20% radiant heat compared to 60% for a low temperature horizontal radiant panel, and as a greater RTA of 20 K is acceptable for a vertical surface such as a hot water radiator then the effect of a radiator on thermal comfort can be less than a horizontal radiant panel. The designer should not neglect this and should consider the layout and setting out of radiators taking account of the use of the space and location of occupants.

To avoid discomfort and to conserve energy BS EN 15251 requires that for a category III building the vertical air temperature difference in the space during the heating season should be less than <2 K/m in the occupied zone. It will be necessary to limit the surface temperature of ceiling mounted radiant panels in classrooms or offices and in normal height teaching spaces to achieve this. Where radiant panels are used in high spaces over 4m in height measures should be taken to reduce stratification.

[69] Hot water radiators are the most commonly used type of heat emitter in classrooms.

7.5 Underfloor heating

A floor that is too hot will cause thermal discomfort. The temperature of the floor, rather than the material of the floor covering, is the most important factor for foot thermal comfort. The BS EN ISO 7730 standard gives the allowable range of floor temperature for Category III as below 31°C. However, there are frequent complaints by school staff of swollen feet and tiredness from underfloor heating in schools and for this reason, the maximum recommended surface temperature has been reduced from the values quoted in EN 15251. This is in line with the advice given in PD CR 1752 that floor temperatures higher than 26 °C should be avoided. This is particularly important where there are nursery-age pupils or pupils with complex health needs, where there is low activity and where pupils are likely to be sitting on the floor. In these cases, one solution is a self-regulating underfloor heating system set to 23ºC to 24ºC maximum surface temperature with a supplementary heating system.

The following categories apply to underfloor heating

Table 7.7: Categories applying to underfloor heating

Type of space/activity[b]	New Build Comfort category and maximum floor surface temperature	Refurbishment Comfort category and maximum floor surface temperature
Teaching and learning, drama, dance, exams, multi-purpose halls	II (<26 ºC)	III (<29 ºC)
Practical activities such as cooking	II (<26 ºC)	III (<29 ºC)
Sports Halls not used for exams	III (<29 ºC)	IV (<31 ºC)
Working areas, eg, kitchens	IV (<31 ºC)	IV (<31 ºC)
Offices	II (<26 ºC)	III (<29 ºC)
Atria, circulation, reception and corridors - not continuously occupied	III (<29 ºC)	IV (<31 ºC)
Areas for pupils with complex health needs[a]	II (<23 ºC)	II (<23 ºC)

[a] In the case of pupils with complex health needs the temperature should be adjustable to cater for the needs of the pupils. In these cases an assessment of the individual needs must be made. This category applies only to Designated Units or

Special Schools for non-ambulant pupils or those with medical conditions. Local portable heating and cooling may need to be provided for SEN students with temperature sensitivities who are educated in mainstream accommodation.

Under-floor heating should not be used in areas that may be covered with mats (e.g. in SEN rooms), or where regular spillages can cause hygiene and odour problems, ie, in toilets, changing rooms or hygiene rooms, nor in areas where the positions of partition walls are likely to change or fixings are required into the screed for furniture (e.g. lab benches) or equipment (e.g. in Design and Technology).

7.6 Performance standards for the avoidance of overheating

Overheating in classrooms and over-glazed larger spaces such as libraries and learning resource centres is a frequently reported problem in schools as noted by post occupancy and staff surveys. The adaptive thermal comfort method from EN 15251 together with the guidance in CIBSE TM52 '*The Limits of Thermal Comfort'* (Technical Memorandum) and CIBSE KS16 '*How to Manage Overheating in Buildings'* (Knowledge Series) has been adopted by DfE to address the problem of overheating in schools. The adaptive comfort criteria only apply to free running buildings i.e. those without mechanical cooling and with means for the occupants to locally alter conditions i.e. to increase the ventilation rate by means of opening windows or by local room controls. Most schools are free running outside the heating season.

To manage overheating successfully using adaptive thermal comfort it is necessary to allow relaxation of formal dress in hot conditions to encourage individual adaptation to conditions. Where pupils cannot regulate their temperature because of illness or physical disabilities special measures must be taken to accommodate their need for a closely controlled thermal environment and to help them to regulate their temperature e.g. by providing local cooling for their specific needs. This advice should be given to the schools and included in Building User Guides.

The personal factors identified which contribute to the perception of thermal comfort, cannot be directly influenced as part of the design. The provision of adequate ventilation for good indoor air quality and the perception of occupant control will together overcome some personal factors. Such factors as dress codes, activity scheduling, etc., should be considered within the briefing process and discussed with the client/school management team in order for them to better understand how they influence thermal comfort and to help establish policies on such matters. The client/ school management team will then be better able to reduce the risk and impact of overheating in their buildings.

All occupied spaces should be provided with ventilation for warmer weather, preferably by using cross flow natural ventilation or ventilation systems with equivalent ventilation effectiveness and night cooling. This will minimise ventilation opening sizes and eliminate the need for mechanical cooling. Cross-ventilation strategies normally require smaller ventilation openings than for single-sided ventilation reducing draughts and making it easier to meet the acoustic requirements for sound insulation of the building envelope.

Buildings should be assessed for overheating and ventilation openings should be sized using dynamic thermal modelling and the CIBSE DSY1 2020 weather file most appropriate to the location of the school building[70].

Mechanical ventilation should not be the sole method of summertime ventilation in occupied spaces and wherever possible there should be opening windows or vents, with sufficient effective opening area.

As a general rule, in the absence of detailed thermal modelling, openable windows or vents for summertime ventilation should be sized so that the effective area, A_{eff} is at least 3% of the floor area. (Note that depending on the type of opening, this can imply a physical opening area of~5% of the floor area.) Some designs will result in more effective area than others and smaller effective areas may be possible if the design includes some degree of cross ventilation, atrium assisted stack ventilation or fan-assistance which will increase the airflow through openings. In all cases, the rooms need to have enough opening area and flow to comply with the summertime overheating criteria below. See Section 5.5 for definition of $A_{eff.}$

Controls should be provided to enable the teacher to temporarily override the mechanical ventilation in each room to switch it on or off as required.

Where internal blinds are fitted to windows, these should not interfere with ventilation. Care should be taken to avoid flutter caused by ventilation airflow.

The design should allow air movement to be increased during the summer through opening windows or vents, switching on fans, or increasing the rate of mechanical ventilation. Ceiling fans may be used, except in a Special School accommodating pupils who are visually sensitive to the movement or flickering reflections from such fans. There are significant differences between the ventilation effectiveness of various types of windows or ventilation openings. See CIBSE AM 10 '*Natural Ventilation in Non-Domestic Buildings'* (Applications Manual) and Section 5.5 on Ventilation opening areas.

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[70] TM 49 Design Summer Years for London, CIBSE, 2014

CIBSE has published criteria in TM52 to assess overheating in free-running buildings, based on the adaptive comfort model. The DfE requirements set out in this section are based on these criteria.

This approach follows the methodology and recommendations of European Standard EN 15251 to determine whether a building will overheat, or in the case of an existing building whether it can be classed as overheating. The criteria are based on a variable temperature threshold that is related to the outside running-mean dry-bulb temperature.

The designer should carry out an Overheating Risk Assessment (ORA) of free running designs by following the procedure set out in CIBSE Technical Memorandum 52. The design of mechanically cooled buildings should be in accordance with the CIBSE guidelines for air-conditioned buildings.

The designer should calculate the indoor operative temperatures for each of the months where the building is in free-running mode on a frequent (e.g. hourly or half-hourly) basis. The simulation tool used should be capable of calculating Operative Temperature, T_{op} and Running Mean Temperature, T_{op} and T_{rm} are defined in TM52. T_{rm} is a running mean of external air temperature and changes on a daily basis. Calculations should realistically account for the occupancy pattern of the building, heat loads of equipment, and the adaptive behaviour of the occupants. See Section 5 for Design Calculations.

For all new building designs, including major extensions, the recommendations of CIBSE TM52 or EN15251 should be used by the Contractor to establish whether a problem of overheating is likely to occur.

The performance standards are based on the adaptive thermal comfort standards described in CIBSE TM52 and KS16.

For all free-running school buildings, the ORA should be carried out based on the Categories given below in Table 7.7.

Table 7.8 Adaptive thermal comfort category to apply

Type of space/activity[b]	New Build	Refurbishment
Teaching and learning, drama, dance, exams, multi-purpose halls	II	III/IV
Practical activities such as cooking	N/A	N/A
Sports Halls not used for exams	III	IV
Working areas, eg, kitchens	N/A	N/A
Offices	II	III/IV
Atria, circulation, reception and corridors - not continuously occupied	III	IV
Areas for pupils with complex health needs[a]	I	I

[a] In the case of pupils with complex health needs an assessment of the individual needs must be made. Adaptive comfort thresholds may not be applicable and fixed temperature thresholds may need to be used. This category applies only to Designated Units or Special Schools for non-ambulant pupils or those with medical conditions. Local portable heating and cooling may need to be provided for SEN students with temperature sensitivities who are educated in mainstream accommodation.

[b] Local portable heating and cooling may need to be provided where SEN students with temperature sensitivities are educated in mainstream accommodation

The values for the maximum acceptable temperature (T_{max}) being calculated from the running mean of the outdoor temperature (T_{rm}) and the suggested acceptable range, as given in

Table 7.99 below, as follows:

$T_{comf} = 0.33T_{rm} + 18.8$

and $T_{max} = T_{comf}$ + (acceptable range ^{0}C)

Therefore, for category II as defined in Table 7.9, below, where the acceptable range is 3^{0}C:

$T_{max} = 0.33T_{rm} + 21.8$ (See CIBSE KS16 or TM52 for definition of T_{rm}).

Table 7.9 Suggested applicability of the categories and their associated acceptable temperature range for free running buildings (from BS EN 15251:2007, prEN 16789-1: 2015)

Category	Explanation	Suggested acceptable range ^{o}C
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility.	+ 2 / - 3 ^{o}C
II	Normal expectation	+ 3/-4 ^{o}C
III	An acceptable moderate level of expectation	+4/-5 ^{o}C
IV	Low level of expectation. This category should only be accepted for a limited part of the year	>+4/ |-5| ^{o}C

The three criteria for overheating are all defined in terms of ΔT the difference between the actual operative temperature in the room at any time (T_{op}) and T_{max} the limiting maximum acceptable temperature. ΔT is calculated as

- $\Delta T = T_{op} - T_{max}$ (^{o}C)
- ΔT is rounded to the nearest degree (ie for ΔT between 0.5 and 1.5 the value used is 1^{o}C, for 1.5 to 2.5 the value used is 2^{o}C and so on)

Three parameters have been developed which indicate when overheating is likely to be problematic. These standards should be applied outside the heating season and for the hours of 09:00 to 16:00, Monday to Friday, from 1st May to 30th September, including the summer holiday period as if the school was occupied normally through the summer (a lunchbreak 12pm to 1pm with no internal heat gains during this period may be allowed for in classrooms). The three criteria are:

1. the number of hours for which an adaptive thermal comfort threshold temperature is exceeded (total hours of exceedance)
2. the degree to which the operative temperature exceeds the adaptive thermal comfort threshold temperature (daily weighted exceedance).
3. the maximum temperature experienced at any occupied time (upper limit temperature).

The first of these criteria (Criterion 1) defines a minimum requirement for the overheating risk assessment. The two additional criteria (Criterion 2 and Criterion 3) are primarily measures of short-term discomfort and should be reported for information only. If a school design fails to meet Criterion 2 or Criterion 3 then designers should consider potential overheating mitigation measures and indicate which are viable for the project. The use of these three performance parameters together aims to ensure that the design is not dictated by a single factor but by a combination of factors that will allow a degree of flexibility in the design.

These performance parameters will ensure that the design is not dictated by a single factor but by a combination of factors that will allow a degree of flexibility in the design.

Criterion 1 - Hours of Exceedance (H_e):

For schools, the number of hours (H_e) that ΔT is greater than or equal to one degree (K) during the period 1st May to 30th September for the defined hours inclusive shall not be more than 40 hours.

An understanding of how often a building in any given location is likely to exceed its comfort range during the summer months (1st May- 30th September) can provide useful information about the building's thermal characteristics and potential risk of overheating over the range of weather conditions to which it will be subjected. Simple hours of exceedance are something that designers are familiar with and provide a good first assessment of acceptability. The defined hours used are the entire period from 1st May to 30th September for the defined hours of 09:00 to 16:00 excluding weekends. Full occupancy is assumed through the holiday period.

Criterion 2 – Daily Weighted Exceedance (W_e):

To allow for the severity of overheating the weighted Exceedance (W_e) shall be less than or equal to 6 in any one day.

Where $W_e = \Sigma h_e \times wf = (h_{e0} \times 0) + (h_{e1} \times 1) + (h_{e2} \times 2) + (h_{e3} \times 3)$

Where the weighting factor $wf = 0$ if $\Delta T \leq 0$, otherwise $wf = \Delta T$, and h_{ey} = time in hours when $wf = y$

This criterion sets an acceptable level for the severity of overheating, which is arguably more important than its frequency, and sets a daily limit of acceptability and is based on Method B – 'Degree hours criteria' in BS EN15251; 2007. It is the time (hours and part hours) during which the operative temperature exceeds the specified range during the occupied hours, weighted by a factor which is a function depending on by how many degrees the range has been exceeded. The value of the weighting factor is based on the observed increase in the percentage of occupants voting ‘warm’ or ‘hot’ on the ASHRAE scale (overheating risk) with each degree increase in ΔT, the temperature above the comfort threshold temperature.

The value of 6 is an initial assessment of what constitutes an acceptable limit of overheating on any single day. This initial assessment was made from observations of the temperature profiles from case studies of a range of free-running buildings that are perceived to perform well at one end of the range and poorly at the other in regards to limiting overheating. For further information, see CIBSE TM 52.

Criterion 3 - Upper Limit Temperature (T_{upp}):

To set an absolute maximum value for the indoor operative temperature the value of ΔT shall not exceed 4K.

The threshold or upper limit temperature is fairly self-explanatory and sets a limit beyond which normal adaptive actions will be insufficient to restore personal comfort and the vast majority of occupants will complain of being ‘too hot’. This criterion covers the extremes of hot weather conditions and future climate scenarios.

These criteria should be the basis of the thermal modelling of the building, with Criterion 1 defining the minimum requirement for assessing the risk of overheating of school designs.

In addition, the asymmetric radiation from hot ceilings in single storey teaching spaces should be less than 5K in summertime.

In order to achieve this hot air must not be trapped at ceiling level and there must be an adequate means to extract hot air from the ceiling zone. For example, cross ventilation can provide adequate airflow across the ceiling and prevent a layer of hot air from building up beneath the ceiling.

Where, after consideration of such measures and taking account of other factors that could restrict the use of natural ventilation (e.g. air pollution, traffic noise) the designer deems that the heat load is such that cooling is required, the designer should consider low carbon cooling systems in preference to conventional air conditioning. Such systems could include using cool water from boreholes or drawing in air through earth tubes.

Where the designer decides to use mechanical cooling, for example at times of peak summertime temperatures in areas of particularly high equipment heat load, this should be justified on heat load and energy efficiency grounds. It should not be necessary to use mechanical cooling in general teaching spaces with equipment gains of less than 10W/m² or practical spaces where the equipment gains are less than 25W/m², as practical spaces are generally larger and have a lower occupancy gain per square metre than general teaching spaces. Some practical spaces have high heat loads, e.g. some graphics studios and music studios, which may have a high density of more powerful high-end computers.

7.7 Assessment of performance in use

Criteria used to assess performance in use of spaces should be easy for the facilities management team to monitor to ensure that the designs for new and refurbished buildings achieve an acceptable standard of indoor air quality and thermal comfort in each teaching space over the year. This information should be fed back to the designers. It is recommended that air temperatures rather than operative temperatures are used by the school to assess thermal comfort in buildings in use as these are easier for the occupants and facilities management team to understand. If there appears to be a failure using the criteria based on air temperatures decribed below then the contractor or a heating expert should be asked to consider if the building is overheating which will necessitate investigation of operative temperatures and comparison with design predictions. With modern building controls it is relatively easy to monitor the indoor environment by recording temperature and CO_2 as well as energy consumption. This can give the building occupants and facilities management team a greater knowledge and control over their environment.

Performance in use should be monitored in typical north, south, east and west facing classrooms and in other key spaces, such as: atria, dining spaces, libraries, learning resource centres, admin and head teacher's offices, server rooms and reprographics rooms, and recorded as part of soft landings.

7.7.1 Performance in use standard for overheating

The following performance in use criteria is recommended for use in contract specifications:

- It should be possible to demonstrate within spaces that are occupied for more than 30 minutes at a time that, during the school day, the average internal air temperature does not exceed the average external air temperature measured over an occupied day by more than 5ºC; both temperatures being averaged over the time period when the external air temperature is 20ºC, or higher, except when the diurnal temperature range[71] (lowest temperature from the previous night to the maximum daytime temperature the following day) is less than 4ºC.

[71] The diurnal temperature is typically 7°C and is > 4°C on approximately 2/3rds of nights, i.e., except when there are anti-cyclonic conditions.

- The buildings should be able to achieve temperatures within the acceptable range when windows, fans and ventilation systems are operated to reduce summertime temperatures, the space has the intended number of occupants and the internal heat gain from teaching equipment, including computers and data projectors, does not exceed the design heat loads of 15 W/m^2 in teaching spaces and 25 W/m^2 in practical spaces with higher heat loads, for example, computer based music and art or graphics where there are significant numbers of powerful desktop PCs (personal computer).
- Note: these overheating criteria are for the thermal comfort of occupants and are not applicable for equipment such as in server rooms. The extra heat loads from cookers in food technology and Bunsen burners in science that are occur intermittently should be considered separately.

The intention is that the school notifies the Contractor if a space fails the PIU criteria above and the internal recorded air temperatures exceed Cat III as defined in Table 7.7.. The contractor then examines temperature records and investigates whether or not the building is overheating and if the building is performing as designed.

To compare predicted design and measured temperatures it is necessary to measure operative temperatures as well as air temperatures. This can be done using a small black bulb thermometer or specialist electronic instrumentation. See CIBSE KS16 for further information.

It is recommended to inform the facilities management team that there may be a difference between the air temperature measured in the room and the design temperature (operative temperature).

8 Design calculations

Ventilation and thermal comfort design for teaching and learning activities should be proved by modelling for the occupied period. CO_2 levels should be below the required values given in Section 2.4. Calculations at concept design stage and scheme design stage need to be carried out for summer, winter and mid-season design conditions to prove that the design will operate satisfactorily throughout the year.[72]

At the detail design stage it is desirable to use dynamic simulation tools particularly if ventilation is to be used for night cooling.

In addition to the ventilation design for normal teaching and learning activities the ventilation for specialist needs such as science or technology must be considered.

For a natural ventilation system the designer should follow the design steps given in CIBSE AM10.

Designs must provide sufficient openable areas in suitable locations for winter, mid-season and summer conditions; and means by which the occupants can control the openable areas must be provided. The designer should consider the results of the overheating analysis, which may show that higher airflow rates are required for either daytime or night time cooling.

Effective area must be used for the sizing of ventilation openings. See Section 8.5.

8.1 Weather file for overheating risk assessment

CIBSE/Met Office hourly weather data Test Reference Years (TRYs) and DSYs are available for 14 locations across the UK.

The CIBSE DSY1 2020 weather file most appropriate to the location of the school buildingshould be used for the thermal comfort assessment. This does not necessarily mean the nearest location and the file should reflect the most compatible climatic characteristics.

DSY consists of a single continuous year of hourly data, selected from the 20-year data sets (1983-2004) to represent a year with a hot, but not extreme, summer. The selection is based on the daily mean dry-bulb temperatures during the period April–September, with the third hottest year being selected. This enables designers to simulate building performance during a year with a hot, but not extreme, summer.

[72] See CIBSE Guide A (2015) Section 4.2 Ventilation and air quality including equations 4.1 and 4.2

8.2 Mechanical ventilation

Where hybrid ventilation is being considered, the mechanical ventilation element needs to be modelled correctly. If it is supply and extract ventilation then a fixed or demand controlled ventilation rate of outside air can be incorporated in the model. If the system is extract only with openable windows, the model should be set up with a zone exhaust and not an exchange rate to outside. It should be noted that for thermal modelling and overheating assessment purposes mechanical ventilation is classified as 'free-running' in the absence of mechanical cooling and tight temperature control.

8.3 Internal conditions

The modelling assumptions affect the calculation results significantly. For this reason EFA projects are required to use the following default assumptions regarding the internal conditions in the occupied spaces of the school:

- Occupied hours assumed 09:00-16:00, Monday to Friday
- Occupancy, lighting and small power set to zero during lunch hour (12:00-13:00) in all classroom areas
- The school is assumed to be occupied throughout the summer period for modelling of overheating. (This provides a degree of future proofing.)

8.4 Internal gains for overheating risk assessment

Occupancy rates vary depending on the activity present in the room. For a typical classroom 32 occupants should be allowed with each having a sensible heat gain of 70 W and a latent heat gain of 55W (in primary school settings, a lower sensible heat gain of 60W/pupil may be allowed).

Lighting gains in classrooms should be considered to be 7.2 W/m^2 unless calculations e.g. of daylight displacement or product selection shows that lower gain rates are justified. These calculations must include all heat gains such as parasitic loads from dimmers and ballasts.

If daylighting is being used to lower the lighting gain, then this must be justified as being within the software's capability and that it has been properly implemented. If the blinds are included in the window transmission values then the lights should be assumed to be on.

ICT usage is dependent on the room type being investigated. Typically, a classroom will have a maximum ICT gain of 10 W/m^2, with dedicated ICT rooms and practical rooms with more powerful computers having 25 W/m^2. In some rooms, lower equipment gains may be applicable.

For the purposes of modelling summertime overheating to determine the required size of summertime natural ventilation openings, the maximum average air speed to prevent summertime overheating should be assumed to be less than 0.8m/s.

Food technology can be modelled with the same internal heat loads as a standard classroom. The additional load associated with cookers is assumed to be removed by extract hoods where they are fitted and in use. Opening windows should be provided preferably to provide cross ventilation to food technology and science rooms to maximise air flow in summer peak conditions.

8.5 Ventilation opening areas

There are two types of ventilation openings in the thermal envelope of a building, those that are intentional known as purpose provided openings (PPOs) and those that are unintentional known as adventitious openings.

Successful ventilation design requires the correct sizing and location of PPOs. In order to do this the effective area of the PPOs must be determined. The sizing of the PPOs is crucial to the ventilation performance of the building.

Unfortunately, not all standards and references use the same definitions of the effective area of a PPO at present and this leads to confusion and errors in sizing of PPOs. Numerous definitions of opening area are in use in smoke ventilation and natural ventilation texts, British and International standards and software tools. Some of these definitions currently contradict each other.

For clarity, BB101 adopts the definitions recommended by the CIBSE Natural Ventilation Group for free area, effective area and equivalent area[73]. See Annex D: Definition of opening areas.

For the avoidance of errors we recommend that design engineers should stipulate effective area (A_{eff}) on their drawings and ventilation specifications. Manufacturers should report A_{eff} as a matter of best practice to aid selection of the most appropriate PPO. The effective area of windows and ventilators is obtained by testing the appliances in accordance with BSEN 13141 (2004) and should be quoted by

[73] *A review of ventilation opening area terminology*, B.M.Jones, M.J.Cook, S.D.Fitzgerald, C.R.Iddon, Energy and Buildings 118 (2016) 249-258.

manufacturers. In the absence of empirical data from manufacturers, a calculation tool[74] can be used to estimate A_{eff} but it should be used with caution.

For turbulent flow through a PPO as normally occurs in natural ventilation openings in buildings the airflow is governed by the following equation

$$Q = A_{eff}\sqrt{\frac{2\Delta P}{\rho}}$$

Q = turbulent uni-directional airflow rate (m^3/s)
A_{eff} = effective area of PPO (m^2)
ΔP = pressure drop across the opening (Pa)
ρ = density of the air (kg/m^3)

This equation applies where flow is fully turbulent and the coefficient of discharge (C_d) does not depend on the airflow velocity. Where this is not the case as in the case of a single PPO comprised of many small openings in parallel e.g. an insect mesh then caution is required and measurements are needed to establish the relationship between airflow rate and pressure difference.

For fully turbulent flow the effective area of a PPO, A_{eff} is defined as the product of its discharge coefficient and its free area:

$$A_{eff} = A_f \; x \; C_d$$

A_f = Free area of the PPO (m^2), this is simply the physical size of the aperture of the ventilator and does not reflect the airflow performance of the ventilator.

C_d = Coefficient of discharge of the PPO, note that for windows this value changes dependent upon the opening angle and shape.

Some dynamic thermal modelling software use equivalent area, this term simply compares the PPO opening of effective area (A_{eff}) in question with an opening, which is circular and sharp-edged:

$$A_{eq} = \frac{A_{eff}}{C_{do}}$$

A_{eq} = Equivalent area (m^2)

C_{do} = Discharge coefficient of a sharp edged circular orifice, practitioners should check their software documentation for values of C_{do} used, these can vary between 0.60 and 0.65

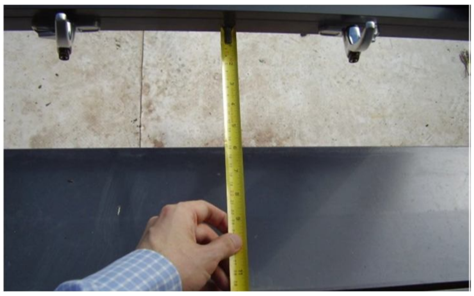
[74] see the Discharge Coefficient Calculator available on DfE website

The more complicated and/or contorted the airflow passages in a ventilator, the less air will flow through it.

If airflow occurs both into and out of a space through a single opening on one side of a building (bidirectional flow), the PPO coefficient of discharge will be reduced to around 40% of the value for unidirectional flow, in part because only half of the ventilation opening is available for airflow into the building. This will impact on the effective area of the PPO. The is explained on pages 45 and 46 of CIBSE AM10 Natural Ventilation, 2005 where it states that in the buoyancy flow equation 4.12 the value of C_d is reduced typically from 0.6 to 0.25. Some software programmes, eg, IES, already allow for this reduction in flow.

Obstructions to the flow of air (eg deep external sills and recesses) must be taken into account, as these will have the effect of reducing the airflow through the opening.

Examples of obstructions include sills, recesses and blinds. They can be seen as another airflow obstruction coefficient, and their presence means their impact on the PPO free area should be accounted for to achieve the required effective area.



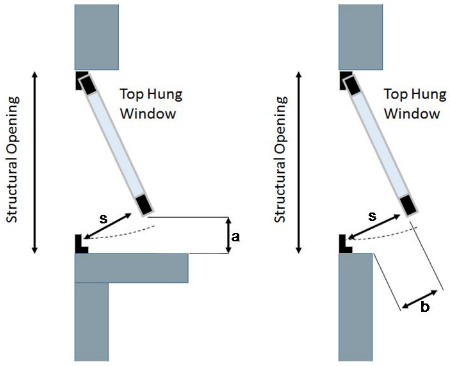


Figure 6.1 Example of ventilation area reduced by the protrusion of the window sill. In the example above top hung windows are opened by the same stroke length, s, but the protruding sill impacts on the free area because a<b

Figure 6.2 Example of ventilation area reduced by the restrictor. Column prevents window opening

Annex A: Carbon dioxide levels in schools

Outside CO_2 concentrations are generally around 380 ppm. For a typical classroom with 30 students and 2 staff, an outdoor air ventilation rate of between 8 and 9 l/s/person corresponds to a carbon dioxide level of around 1000 ppm under steady state conditions depending on the ventilation system. See calculation method given in CIBSE Guide A.[75]

The lowest ventilation rate of 8 l/s/person for schools is also proposed by the results of the HealthVent project[76]. The project also recommended the "health-based reference minimum ventilation rate" of 4 l/s/person, when WHO indoor air quality (IAQ) guidelines are fully respected and the only pollutants are human bio-effluents (CO_2). Therefore, in reality, where the WHO guidelines are not met, rates higher than 4 l/s/person are needed, but after source control measures are implemented.

An outdoor air supply rate of 5 l/s/person corresponds to around 1500 ppm under steady state conditions.

Chatzidiakou et al. (2015) in their work within the Sinphonie project, concluded that simultaneous provision for limiting indoor CO_2 levels and thermal conditions below current guidelines (ie below 1000 ppm and 26°C or 22°C depending on season) can limit indoor airborne particulate matter concentrations below recommended annual WHO 2010 guidelines and may improve perceived IAQ.

According to European Standard EN 15251 – revision (EN16798-1 and -2), the CO_2 levels of 550, 800 and 1350 ppm above the outdoor concentration, correspond to Categories I; II; and III respectively for high; normal; and acceptable moderate levels of expectation, in terms of IAQ[77]. Classification by CO_2 level is well established for occupied rooms, where CO_2 is mainly the product of human metabolism.

The recommended DfE design targets for CO_2 levels given in Section 2.4 correspond to category II for ventilation with an allowance for category III for part of the time for natural and hybrid ventilation solutions.

[75] See CIBSE Guide A (2015) Section 4.2 Ventilation and air quality equations 4.1 and 4.2

[76] http://www.healthvent.byg.dtu.dk/

[77] EN 13779 –revision (EN16798-3 and -4): Category I: High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements such as handicapped, sick, very young children and elderly persons; / Category II: Normal level of expectation;

The reason for the difference in design maximum target levels for CO_2 for the two types of system is that the variability of natural ventilation driving forces is much greater than that of a mechanical ventilation system.

Figure A.1 shows how the CO_2 levels achieved with demand controlled room-based mechanical ventilation vary.

With demand control of CO_2, mechanical system fan speeds accelerate rapidly with rising CO_2 levels, to stay within the allowable range for IAQ. When occupancy reduces during break times for example, fan speeds slow down within their turndown range, giving resultant power savings.

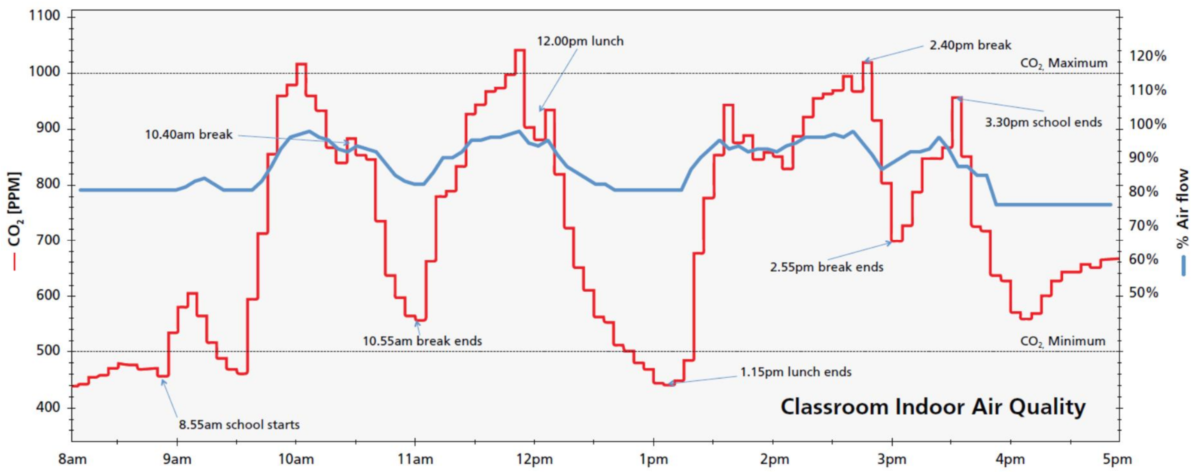


Figure A.1 Typical changes in CO_2 levels with demand controlled room-based mechanical ventilation systems, Graph provided by SAV Airmaster

Natural ventilation is much more variable than mechanical ventilation through the year due to changes in the driving forces caused by changing weather conditions. The wind effect varies and so does the stack or buoyancy effect whereas the maximum driving force from mechanical systems is a function of only the fan speed.

The graphs below show how CO_2 levels can vary over the course of a day in a naturally ventilated classroom with manually openable windows during the heating season and during the summertime. The graphs show typical weekly CO_2 traces from February and July from a secondary maths classroom in the north west of England. The red dashed line represents the average occupied CO_2 concentration. There are a number of reasons that explain the difference in CO_2 levels between February and July.

1. In July the vents are opened wider to deliver increased ventilation for cooling purposes resulting in much lower CO_2 concentrations.

2. Occupants have been shown to be much more likely to open windows in response to high temperatures than in response to high CO_2 levels; and
3. Cold draughts in winter make it much less likely that occupants will open the windows.

February

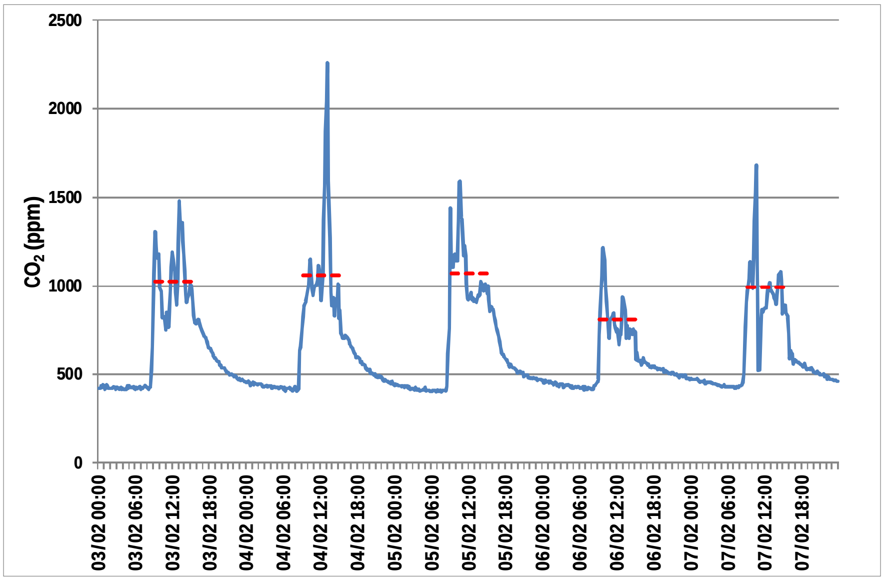


Figure A.2 Average occupied CO_2 concentration in February, for a secondary maths classroom in a school in the North West of England. Graphs provided by SE Controls

July

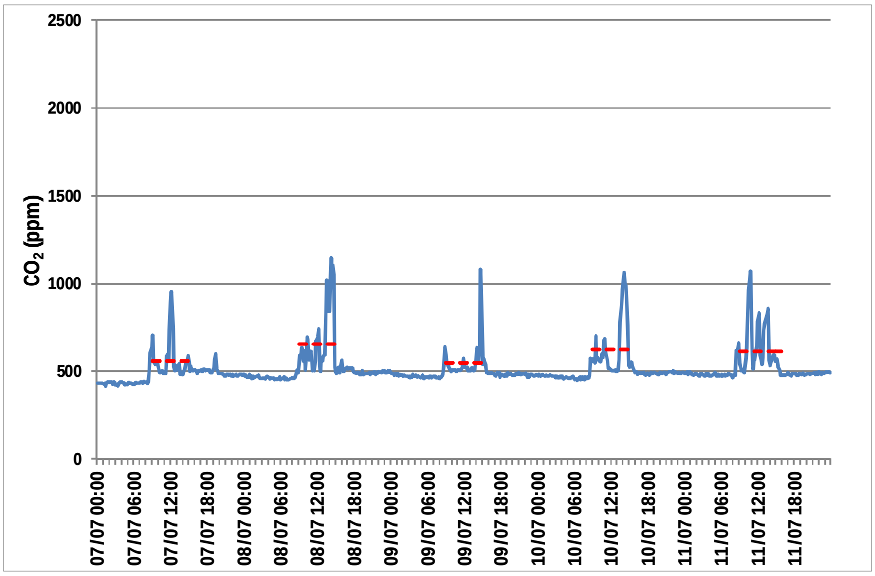


Figure A.3 Average occupied CO_2 concentration in July, for a secondary maths classroom in a school in the North West of England. Graphs provided by SE Controls

The graphs in Figure A.4 and Figure A.5 show the amount of time during the occupied periods that the carbon dioxide level exceeds different CO_2 levels for two schools with fan-assisted pre-mixing natural ventilation systems that do not rely on ventilation from opening windows in wintertime. The schools were designed to the current CO_2 levels for a hybrid or natural ventilation system. This shows that in practice the current maximum design target CO_2 levels (1500ppm maximum target daily average) can achieve excellent air quality over the course of a winter or the whole year.

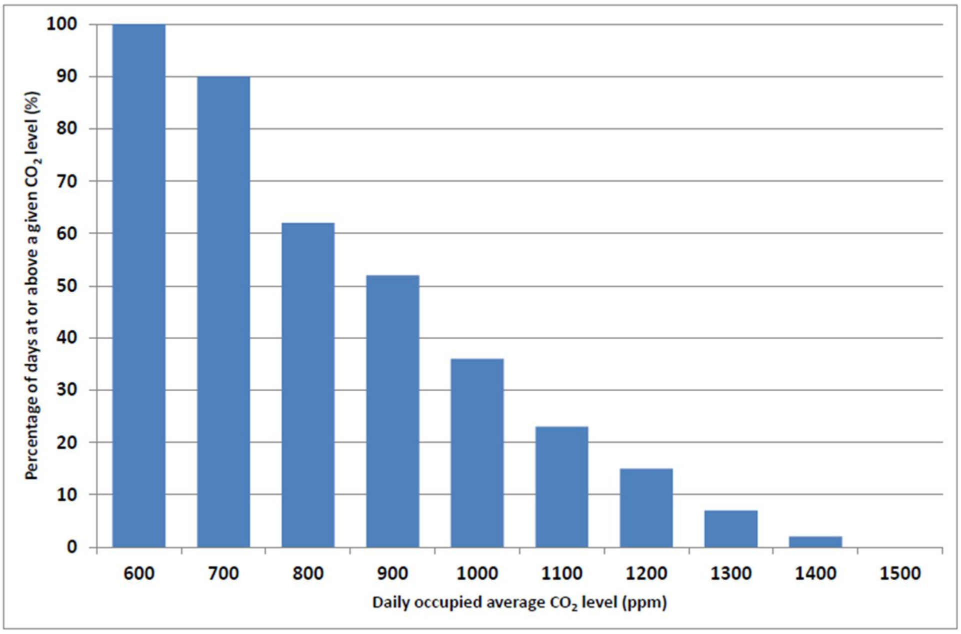


Figure A.4 A Secondary School all year CO_2 monitored results. Graph provided by Breathing Buildings

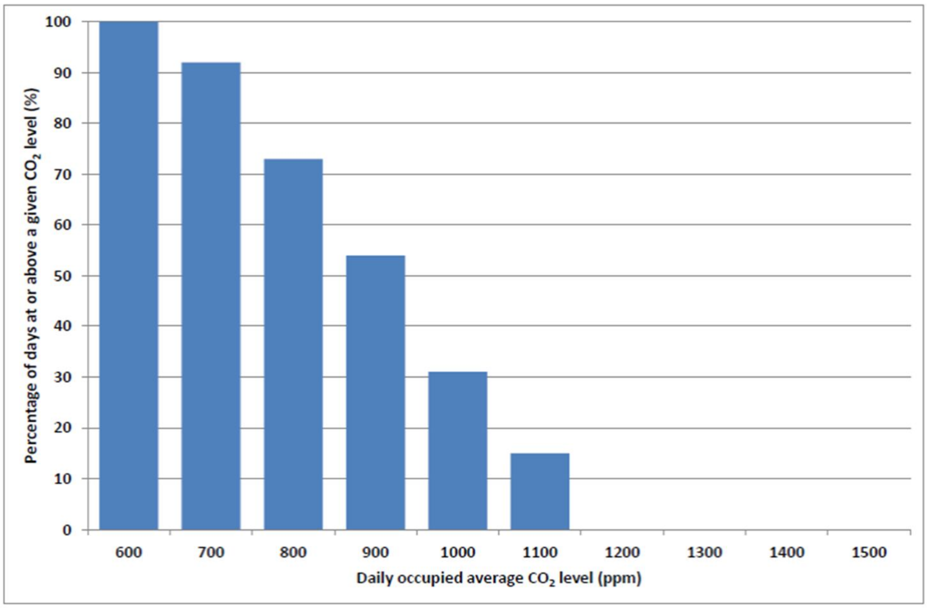


Figure A.5 A Preparatory School for age up to 13 years wintertime CO_2 levels monitored. Graph provided by Breathing Buildings

The elimination of cold draughts during wintertime and in mid-season conditions is a major design consideration for classroom ventilation systems as the spaces have relatively low ceilings and high flow rates are required because of the density of occupation. Many naturally ventilated schools that can achieve the air changes rates in winter do not because teaching staff do not open the windows during the cold weather because the open windows would cause uncomfortable cold draughts.

If the maximum average design carbon dioxide level for natural ventilation systems was reduced to 1000ppm with a maximum of 1500ppm, as specified for mechanical ventilation systems, a much longer length of high level opening would be required to avoid cold draughts in winter. There is a practical limit to the length of this opening so that the cost of lowering the CO_2 target becomes increasingly expensive and impractical in the case of natural ventilation systems.

Hybrid systems are now the preferred choice in many schools for lower spaces such as classrooms as it is economic and practical to use demand controlled mechanical/fan-assisted systems for mid-season and wintertime and to use natural ventilation without cold draughts to complement the mechanical/fan-assisted ventilation in mid-season and for the peak summertime conditions. Windows can be used at most times of the year to supplement the mechanical/fan-assisted ventilation by opening the windows as far as possible without causing thermal discomfort with demand controlled mechanical/fan-assisted ventilation supplying the balance of the ventilation required; this leads to energy savings compared to a system using only windows for ventilation.

Providing summertime ventilation though a purely mechanical system requires very high flow rates for a classroom and exposed thermal mass. This is only recommended where the external noise level is very high or there is very severe pollution. Even in this case some manually openable windows or vents should be provided for occasional use.

In heavily polluted areas an alternative solution is to provide fan coil units for summertime cooling. Mechanical ventilation with fan coil units can have a low capital cost but is not well suited to most schools due to the complexity of the controls, the maintenance required and the high running cost.

In higher spaces, e.g. halls, where dumping of cold air from high-level windows or vents is may not occur due to the height of the space, natural ventilation with or without mixing is often sufficient to meet the ventilation needs.

Annex B. Indoor air pollutants, sources and health effects[78]

Table B.1 Indoor air pollutants, sources and health effects

Pollutant	Sources	Health effects
Particulate matter (PM2.5 and PM10)	Outdoor combustion particles arise from industrial emissions, road vehicle exhausts (diesel/gasoline), non-road vehicles (e.g. marine, construction, agricultural and locomotive), heating exhausts (from coal or wood), forest fires, and other open fires or incineration (e.g. garden waste and burning rubbish). The extent to which these outdoor sourced particles affect a school building's indoor air depends on the building's location, how close it is to the outdoor sources, the main wind direction relative to the sources, the type of ventilation system in use, the proportion of outdoor air in the indoor air mixture, and the location of the air intakes. Indoor combustion particulate sources include heating appliances, dry process photocopying machines, cooking appliances and tobacco smoke.	Epidemiological studies suggest that exposure to PM air pollution is associated with both short- and long-term health effects in humans. In particular, PM has been related to an increased risk of morbidity and mortality from cardiovascular diseases, lung disease, asthma, and other respiratory problems. Sub-populations, such as children, the elderly and people with respiratory diseases (e.g. chronic obstructive pulmonary disease, acute bronchitis, asthma, pneumonia), are at increased risk of health effects from PM exposure. Children are especially sensitive to air pollution because they breathe 50 % more air per kg of body weight than adults. PM2.5 poses the greatest health risk and can aggravate existing respiratory conditions, such as asthma and bronchitis. It has been directly associated with increased hospital admissions and emergency room visits for heart and lung disease, decreased lung function, and premature death. Short-term exposure may cause shortness of breath, eye and lung, irritation, nausea, light headedness, and possible allergy aggravations. Smoking is not permitted in schools.
Benzene	Benzene in indoor air comes from outdoor air (exhaust fumes from mobile sources) and from indoor sources such as combustion (heating,	Benzene causes central nervous system damage after acute exposure. Chronic benzene exposure may result in bone marrow depression. The major health risk associated with low

[78] Based on table from the SINPHONIE project: Kephalopoulos et al., 2014 -)

Pollutant	Sources	Health effects
	cooking, incense burning, smoking, etc.), attached garages, building materials, vinyl, rubber and PVC floorings, nylon carpets, furniture and the storage of solvents. Benzene is currently not used in school science experiments.	level exposure to benzene is leukaemia and the strongest link in humans is with acute non-lymphocytic leukaemia (ANLL). The lowest level of exposure at which an increased incidence of ANLL among occupationally exposed workers has been reliably detected appears to be in the range of 32 to 80 mg/m^3. The estimated unit risk of leukaemia per 1 µg/m^3 is 6 × 10^{-6}, and an excess lifetime risk of 1/10 000, 1/100 000 and 1/1000 000 are 17, 1.7 and 0.17 µg/m^3, respectively.
NO_2	The most important indoor sources of NO_2 include gas appliances, kerosene heaters, woodstoves and fireplaces without flues. Ambient air (car exhausts) is a strong contributor to indoor concentrations of NO_2. The main ambient sources of nitrogen oxides (NO_x) include the intrusion of stratospheric NO_x, bacterial and volcanic action, and lightning. Fossil fuel power stations, motor vehicles and domestic combustion appliances emit nitric oxide (NO), which is a reactive compound that is oxidised to NO_2.	NO_2 is an oxidising agent that is highly irritating to mucous membranes, and causes a wide variety of health effects. Most studies demonstrate substantial changes in pulmonary function in normal healthy adults at or above NO_2 concentrations of 2ppm. Asthmatics appear to be responsive at about 0.5 ppm and subjective complaints have been reported at that level. NO_2 increases bronchial reactivity as measured by pharmacological bronchoconstrictor agents in normal and asthmatic subjects, even at levels that do not affect pulmonary function directly in the absence of a bronchoconstrictor. Epidemiological studies suggest that children who are exposed to combustion contaminants from gas stoves have higher rates of respiratory symptoms and illness than other children. There have been concerns that infants may be at a higher risk of symptoms of high indoor NO_2 levels because of their high respiratory rates in relation to body size and because they spend a large proportion of their time indoors.
Formaldehyde	Formaldehyde is released from most wood-based materials, used extensively as a preservative, disinfectant and biocide, as a component of glues, varnishes, printing materials, textile treatments, permanent markers, automotive equipment, and	Formaldehyde has a pungent odour and has irritating properties which cause discomfort. The symptoms displayed after short-term exposure to formaldehyde are: irritation of the eyes, nose and throat, together with exposure-dependent discomfort, lachrymation, sneezing, coughing, nausea and

Pollutant	Sources	Health effects
	dozens of other products. It is also formed in combustion processes, tobacco smoking in particular, by the air chemistry of terpenes, which are contained in fragrances and air fresheners, and in particular as a product of the hydrolysis of formaldehyde based resins (mostly urea formaldehyde, phenol formaldehyde, and melamine formaldehyde) resins. Because of its multitude of indoor sources, formaldehyde is found ubiquitously in almost all indoor environments (hence in school buildings as well) at levels that exceed outdoor concentrations by an order of magnitude or more. Indoor concentrations of formaldehyde are influenced by temperature, humidity, ventilation rate, age of the building, product usage, presence of combustion sources, and the smoking habits of occupants.	dyspnoea. Children have been reported to be more sensitive to formaldehyde exposure. In December 2012, the European harmonised classification and labelling system classified formaldehyde as a Category 1B carcinogen. Note: A Category 1 substance is known or presumed to have carcinogenic/mutagenic potential for humans. For category 1A, the assessment is based primarily on human evidence; for category 1B, the assessment is based primarily on animal evidence. Smoking is not permitted in schools.
Naphthalene	Naphthalene is an intermediate in the production of phthalate plasticisers, synthetic resins, phthaleins, dyes, pharmaceuticals, preservatives, celluloid, lampblack, smokeless powder, anthraquinone, indigo, perylene, and hydronaphthalenes. Crystalline naphthalene is used as a moth repellent in mothballs and as a solid-block deodoriser for toilets. It is also used in the production of insecticides. Wood smoke, fuel oil and petrol also contain naphthalene. Naphthalene emissions into the atmosphere mainly originate from fugitive emissions and motor vehicle exhausts. Spills into land and water during the storage, transport and disposal of fuel oil and coal tar are lost and released to the atmosphere due to volatilisation, photolysis,	The main health concerns of exposure to naphthalene are respiratory tract lesions, including tumours in the upper respiratory tract. Based on the IARC classification, naphthalene is possibly carcinogenic to humans (Group 2B). Smoking is not permitted in schools.

Pollutant	Sources	Health effects
	adsorption, and biodegradation. Usual indoor sources of naphthalene are unvented kerosene heaters and tobacco smoke.	
Carbon monoxide	CO is widely generated indoors by unvented combustion appliances, particularly if they are operated in poorly ventilated rooms. Tobacco smoke is also an important source of indoor CO pollution.	Exposure to high levels of carbon monoxide is a frequent cause of fatal accidents. At lower levels, exposure leads to reduced exercise ability and increased risk of ischemic heart disease. Epidemiological studies involving large population groups, where exposures were generally at relatively low carbon monoxide levels, have demonstrated increased incidences of low birth weight, congenital defects, infant and adult mortality, cardiovascular admissions, congestive heart failure, stroke, asthma, tuberculosis and pneumonia (WHO 2010). Smoking is not permitted in schools
Ozone	Outdoors, particularly in urban settings near areas of high traffic, levels of ozone can become sufficiently elevated to cause health problems, particularly in sensitive individuals, such as elderly people or asthmatics. Since outdoor air is drawn into buildings through ventilation systems or open windows, elevated outdoor ozone levels can cause elevated levels indoors. A number of indoor sources can increase ozone levels even more and have been known to cause respiratory problems. The major indoor sources of ozone are office machinery (particularly electrical equipment), computer terminals, laser printers, and photocopiers. Ozone is sometimes used for swimming pool water treatment. High densities of such equipment and/or deficiencies in ventilation systems can lead to	Being a strong oxidant, ozone can exert various physiological effects on pulmonary (lung) function, including reductions in lung function, air-exchange rates, and airway permeability. Ozone can also act as an irritant. The health impacts of exposure to elevated ozone levels include eye irritation, shortness of breath (dyspnoea), coughing, asthma, excessive mucous production, mucous membrane irritation, and chest pain upon inhalation. Subjects such as asthmatics and those with allergic rhinitis may be particularly susceptible to the effects of elevated ozone.

Pollutant	Sources	Health effects
	elevated ozone levels that may cause adverse health effects. 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.	
d-Limonene	There is widespread use of d-Limonene in numerous consumer products used in indoor environments. It is the familiar lemon smell in many cleaning products and fragrances.	Potential hazards of exposure to d- Limonene are eye and airway irritation. Scientific findings suggest that reactions between unsaturated volatile compounds (e.g. limonene, α-pinene, styrene) and ozone or hydroxyl (OH) radicals produce chemically reactive products more likely to be responsible for eye and airway irritation than the chemically non-reactive VOCs usually measured indoors. It is therefore expected that an exacerbation of health effects will follow the concomitant presence of ozone in indoor environments.
Trichloroethylene	Consumers may be exposed to TCE by using wood stains, varnishes, finishes, lubricants, adhesives, typewriter correction fluid, paint removers and certain cleaners, where TCE is used as a solvent. Contaminated water or soil may also contribute to indoor pollution through TCE.	Exposure to TCE increases the risks of liver, kidney and testicular cancer as well as non-Hodgkin's lymphoma. Since there is sufficient evidence that TCE is a genotoxic carcinogen, all exposures indoors are considered relevant and no threshold can be determined. IARC has classified TCE as probably carcinogenic to humans (Group 2A) based on sufficient evidence in animals and limited evidence in humans.
Tetrachloroethyle ne	Consumer products that may contain TCA include adhesives, fragrances, spot removers, stain removers, fabric finishes, water repellents, wood cleaners, motor vehicle cleaners and dry-cleaned fabrics. Consumer products described above are sources of indoor TCA exposure.	Exposure to TCA can affect the central nervous system, eyes, kidney, liver, lungs, mucous membranes and skin. Carcinogenicity is not used as an end-point, since there are no indications that TCA is genotoxic and there is some uncertainty about the epidemiological evidence as well as the relevance of the animal carcinogenicity data to humans. However, because of the remaining uncertainty about the

Pollutant	Sources	Health effects
	Contaminated drinking water may be a source of indoor TCA exposure when taking a shower or washing dishes.	carcinogenicity of TCA, it should be kept under review. IARC concluded that there is evidence for consistently positive associations between exposure to TCA and the risks for oesophageal and cervical cancer and non-Hodgkin's lymphoma. TCA is classified by IARC as a Group 2A carcinogen (probably carcinogenic to humans).
Radon	The main source of indoor radon is the radon produced by the decay of naturally occurring radium in the soil subjacent to a building.	The most important route of exposure to radon and its decay products is inhalation. IARC classified it as a Group 1 human carcinogen in 1988, while the WHO considers it to be the second cause of lung cancer after cigarette smoking.

Annex C. Guidance on construction products and materials in school buildings

This Annex is based on the European Commission funded SINPHONIE project (Kephalopoulos et al, 2014). Due to increasing requirements for energy efficiency in EU buildings, it has become essential to use low-emission construction products and materials in school buildings. This makes it possible to control indoor air pollution and keep it at levels that minimise the associated risks to the health of school students and staff while rationalising the use of ventilation to dilute unacceptable levels of indoor air pollutants. This is recommended as part of a holistic approach concerning the design, operation and maintenance of sustainable school buildings in Europe. Significant effort is currently being put into advancing innovations towards sustainable buildings. This aims to: (a) reduce the overall impact of the built environment on human health and the natural environment by ensuring the efficient use of energy, water and other resources; (b) protect the health of occupants and improve educational outcomes; and (c) reduce waste, pollution and environmental degradation.

The choice of floor covering (wood/wood-based products, flexible and ceramic floor coverings) will depend on the intended use of the area and the necessary standard required. For example, ceramic floor coverings should be used anywhere where coverings must prove durable given constant, heavy use and frequent cleaning (e.g. sanitary facilities). Only floor coverings that can be damp wiped should be used following the new construction or renovation of school buildings.

Textile floor coverings are not recommended for use in school buildings because of the comparatively high cost of cleaning (in terms of time and money), and also their considerable contribution to the re-suspension of indoor particulate matter (PM).

Solvent-free, low-emission floor covering adhesives are preferable for all types of floor coverings (flexible floor coverings, carpets, parquet).

Only low-formaldehyde or formaldehyde-free eco-labelled furniture products should be used in school buildings.

Before painting and varnishing, a check should be made as to whether the work requires the use of varnishes, or whether emulsion paints could be used instead. Emulsion and latex paints are suitable for mineral sub surfaces (walls and ceilings).

Where possible low solvent paints should be used but where there is a good reason to use a stronger solvent-based paint a considerable period of aeration and ventilation should be provided before occupation by staff and students.

Low-pollutant varnishes or wood glazes are the most suitable for protecting the surfaces of non-load-bearing timbers in indoor areas (classrooms, offices). Low pollutant varnishes to protect the surfaces of wooden components or objects exposed to the weather are also available on the market.

Surface-treating agents with a high solvent content should not be used for varnishing parquet. Water-based surface-treating agents (water seals) based on acrylic or polyurethane resin should be used instead.

Emulsion paints are suitable for covering large areas of walls, ceilings and façades in school buildings. Only low-emission wall paints should be used in indoor areas of school buildings (e.g. matt emulsion paints, silk gloss and gloss latex paints and silicate emulsion paints).

Preservatives included in the contents declaration on cans of water-based paints should be noted, to protect allergy sufferers.

Annex D. Definition of opening areas

A description of the geometry of an opening and its resistance to airflow are required so that the performance of a system can be established using a modelling tool. The vast majority of ventilation openings in buildings can be described as *sharp-edged*. This means that they are thin when compared to their circumference. Figure 1 shows a perfectly round hole in a thin sheet of metal, known as an orifice, with a thickness L (m). It is very easy to measure the diameter, d (m), of this opening and to identify it as *sharp-edged* when L/d < 2. It is also easy to calculate its area, known as a *free* area because it identifies the area free from obstruction.

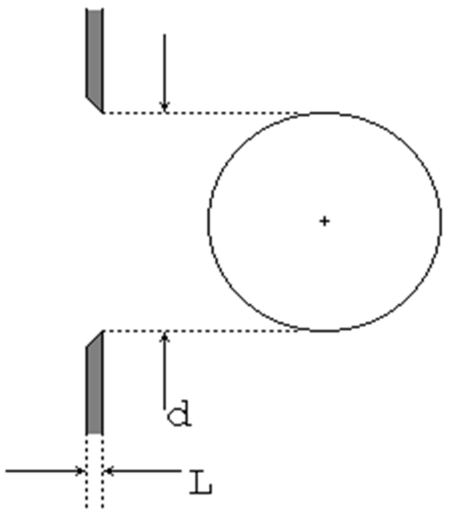


Figure 1: A *sharp-edged* orifice

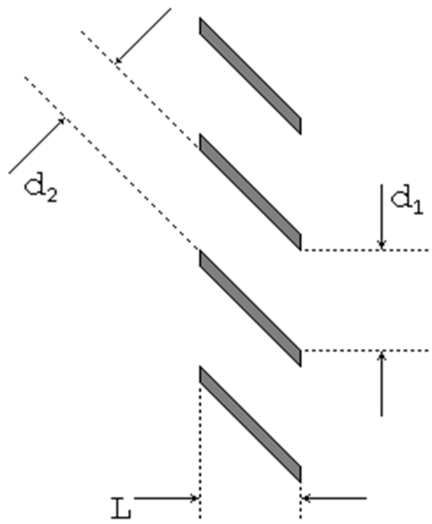


Figure 2: Ambiguity in opening *free* area

Figure 2 shows a louvered opening where two possible lengths could be used to calculate a *free* area and either can be correct so long the appropriate equation is used and workings are clearly presented. However, this ambiguity makes a *free* area a problematic metric because it has the potential to introduce error into the design process.

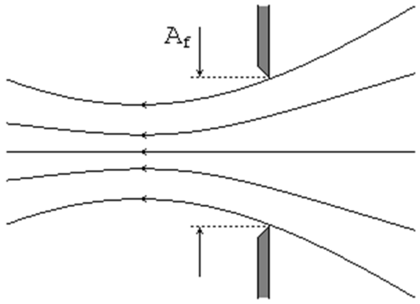


Figure 3: Streamlines through a *sharp-edged* orifice

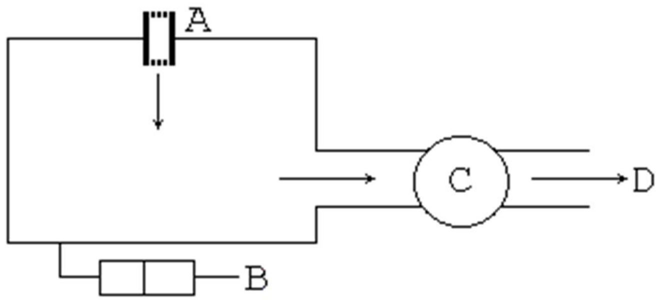


Figure 4: Test chamber. A, ventilation opening; B, anemometer; C, flow meter, D, airflow to fan

For turbulent flow through an opening as normally occurs in natural ventilation openings in buildings the airflow is governed by the equation (1).

The airflow rate, Q (m^3/s), through any sharp-edged opening is proportional to its *free* area, A_f (m^2), the pressure drop across the opening ΔP (Pa), the density of the air ρ (kg/m^3), and the shape of the opening.

$$Q = C_d A_f \sqrt{\frac{2\Delta P}{\rho}} \qquad (1)$$

Here, C_d is a dimensionless discharge coefficient that accounts for the constriction of streamlines after flow passes through an opening; see Figure 3. Accordingly, $0 < C_d < 1$ and a discharge coefficient, C_{d_o}, of the standard circular sharp-edged orifice shown in Figure 1 is often, but not always, given as C_{d_o} = 0.61. For *sharp-edged* openings with a fixed *free* area, such as a vent, the C_d can be considered constant in most cases. Then A_f and C_d can be combined into a single term, known as an *effective* area, A_{eff} (m) where

$$A_{eff} = C_d A_f. \quad (2)$$

Another approach is to calculate the *equivalent* area, A_{eq} (m), of a hypothetical circular sharp-edged orifice that allows air to pass at the same volume flow rate as a ventilation opening with area, A_f, at an identical pressure difference where

$$A_{eq} = \frac{C_d A_f}{C_{d_o}} = \frac{A_{eff}}{C_{d_o}}. \quad (3)$$

However, this process could introduce uncertainty into the value of A_{eq} because there is no standard value of C_{d_o}. Therefore, an *effective* area, A_{eff}, is the most parsimonious metric that has the least uncertainty in its value and is the preferred unit of opening area. The area terms defined here agree with those given by Approved Document F.

The *effective* area, A_{eff}, for a specific ventilation opening is measured using a standard test rig (see Figure 4) described by EN13141-1. It comprises a sealed chamber to which an opening is attached, a fan, a long duct, and an anemometer. The A_{eff} is measured under still external air conditions with uniform density so that the airflow through the opening is exclusively generated by a fan. The flow rate, Q, is systematically varied and ΔP is recorded at each interval. A_{eff} is determined by regression using Equations (1) and (2).

Some ventilation openings, such as windows, have a variable A_f and so an indication of the change in A_{eff} with opening angle should be given. For longer openings that are not *sharp-edged* (where L/d > 2), such as a stack, or for a *tortuous* opening that contains an insect mesh or an acoustic baffle, it is unlikely that A_{eff} can be considered constant over the operational range of pressure differences of the device (normally ΔP=0Pa to ΔP=10Pa) and so a manufacturer should be able to demonstrate any variation.

In the absence of empirical data, a calculation tool can be used to estimate A_{eff} (see the DfE website), but it should be used with caution.

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