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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.

Sections 3 to 5 provide detailed guidance on how to design schools to achieve the required performance for ventilation indoor air quality and thermal comfort.

Acknowledgements

DfE would like to thank the members of the advisory group listed below, and the organisations: Public Health England, the Health and Safety Executive, the Institution of Gas Engineers and Managers (IGEM), CLEAPSS, the Design and Technology Association (DATA), the Chartered Institution of Building Services Engineers (CIBSE) and the Institute of Local Exhaust Ventilation (ILEV) for their help in drafting this document.

Disclaimer

Expiry/review date

This advice will next be reviewed in 2021.

Who is this advice for?

This advice is for those involved in the design, specification and construction of school buildings.

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.

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Glossary

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

“Natural ventilation” is defined as ventilation where the driving force is buoyancy or wind.

“Mechanical ventilation” is defined as ventilation where the driving force 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

This Building Bulletin describes the environmental factors that affect ventilation. It describes the regulations that apply in Section 2, on page 15.

These guidelines are aligned with the latest drafts of BS EN 15251 'Indoor environmental inputs for design and assessment of energy performance in buildings addressing indoor air quality, thermal environment, lighting and acoustics' and BS EN 13779 'Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems' and international comfort standards ISO 7730: 2005 and PD CR 1752: 1999 CEN Technical Report 'Ventilation for buildings – Design criteria for the indoor environment'.

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].

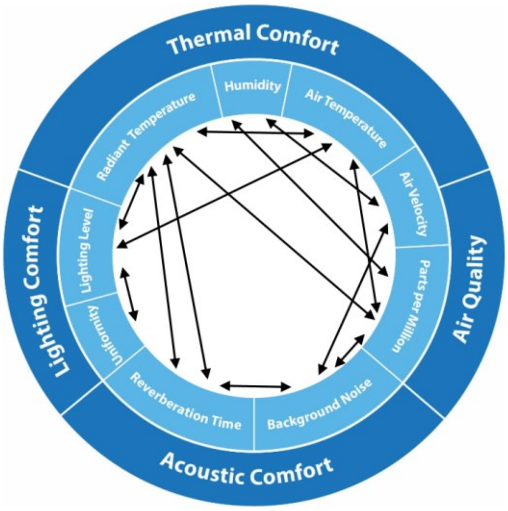

Figure 1.1 The environmental circle

Building Bulletin 93 Acoustic Design of Schools: Performance Standards, Department for Education, 2015 and the IoA/ANC Acoustics of Schools: a design guide, November 2015 give the design criteria for acoustics.

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[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.

CIBSE Lighting Guide LG5, Lighting in Education gives the criteria for lighting design in schools. The EFA (Education Funding Agency) daylight and lighting systems design guide and the EFA Window and Door design guide provide further guidance.

Design for IEQ is the basis of BS EN 15251. A holistic multi-disciplinary approach is needed to prevent unintended consequences of design driven by low energy or other overarching design drivers[5].

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
- 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.

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[6] is essential in this and post occupancy Building Performance Evaluation (BPE) provides the necessary feedback into the specification of future design criteria.

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[5] 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

[6] BSRIA, 2009. Soft Landings Framework

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, these general teaching spaces use hybrid or mixed mode systems that make use of a mixture of mechanical and natural ventilation.

Pure 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)

Pure 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

Depending on the type chosen, the fans may have to overcome natural driving forces of the wind and stack effect.

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.
These types of system use pure natural ventilation components, coupled with systems such as:

- Fans to aid mixing in colder weather
- 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
- In-room cooling systems

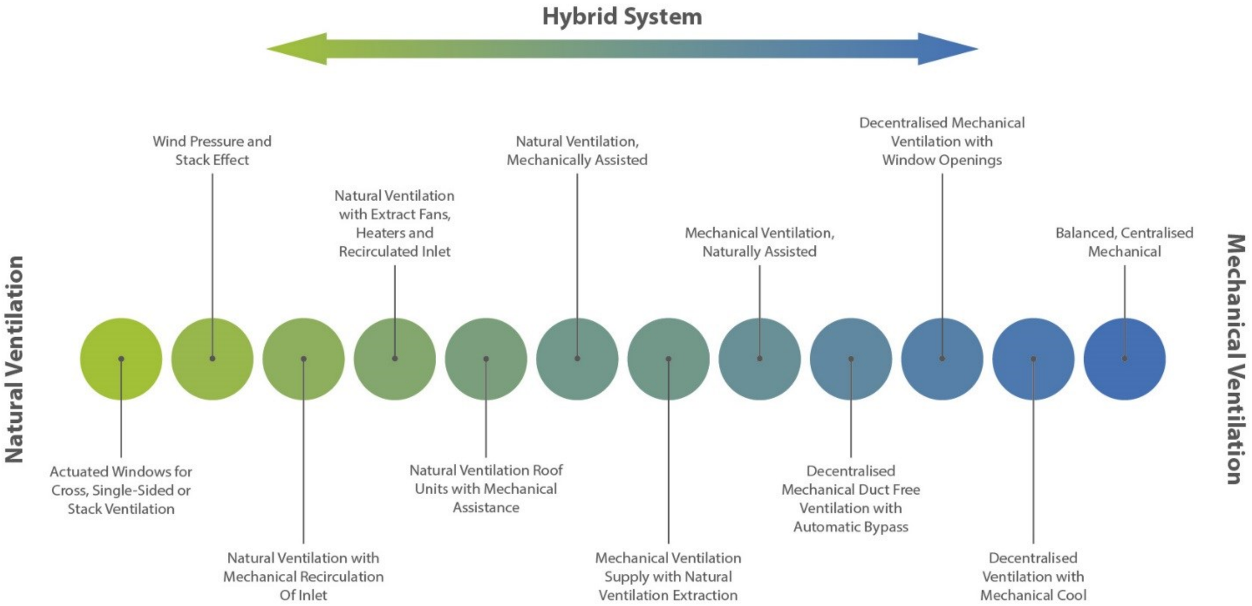

Figure 1.2 Types of ventilation system

2 Regulatory Framework

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.

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

Criterion 3 of Approved Document L2A, 2013 edition, sets out the 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”.

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 (2016) 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, 2013 edition, provides guidance on insulating pipework and ductwork. The guiding principle is that heat losses from uninsulated pipes should only be permitted where the heat can be demonstrated as ‘always useful’.

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:

“… (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, 2004 Edition incorporating 2010 and 2013 amendments.

2.1.3.1 Radon remediation systems

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 www.ukradon.org.

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.

Temporary buildings are exempt from the Building Regulations. Temporary buildings are defined in Schedule 2 to the Building Regulations as those, which are not intended to remain in place for longer than 28 days. In the context of schools, prefabricated buildings commonly referred to as ‘temporary’ buildings that are normally in place for longer than 28 days are therefore subject to the Building Regulations. However, the Building Regulations do permit some relaxation of this requirement when buildings that were designed to a previous version of the Building Regulations are relocated.

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[7], the guidance in this document applies to the building, or that part of the building, which has been subject to the change of use. For example, conversion of an office building or factory into a school building would constitute a material change of use. The requirements relating to radon also apply to new extensions to buildings in relevant areas.

Where the ventilation performance of an existing building needs to be upgraded, or when the building is being refurbished for other reasons, the designer should aim to achieve the standards for new buildings. It is recognised, however, that it would be uneconomic to upgrade all existing school buildings to the same standards as new school buildings.

The Building Regulations define windows as a controlled fitting and, therefore, when windows in an existing building are replaced, the work should comply with the requirements of Building Regulations K[8] (or Part N in Wales), and Part L and N.. Also, after the building work, compliance with other applicable parts of Schedule 1 (Parts B, F and J) should be at the same level or better than it was prior to the work.

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 the prevention of summertime overheating need to be considered. The opportunity to replace excessive glazing and to reduce solar gains and increase ventilation rates should not be overlooked during building work, for example, using opaque panels for additional secure ventilation. Window restrictors are required on some windows for security or to prevent hazards. Window and door design is covered in detail in Education Funding Agency (EFA) technical guidance on external fabric design.

Installers of replacement windows in schools who are registered with a relevant competent person scheme[9] 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:

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

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

[9] www.gov.uk/competent-person-scheme-current-schemes-and-how-schemes-are-authorised

- The Workplace (Health, Safety and Welfare) Regulations 2013; and
- The Control of Substances Hazardous to Health (COSHH) Regulations. See HSG 258.

The Management of Health and Safety at Work Regulations 1999 apply to schools.

For the vast majority of above ground workplaces including schools the risk assessment should include radon measurements in appropriate ground floor rooms where the building is located in a radon Affected Area[10].

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.

(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.

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[10] http://www.hse.gov.uk/radiation/ionising/radon.htm#legalrequirements

- 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 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.
3. As well as designing to meet the maximum carbon dioxide criteria given in paragraphs 1 and 2 above; 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 3.7 for definitions of categories.

Except as described in Section 2.11 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. Where possible carbon dioxide sensors should be used to save energy through monitoring and demand control of ventilation systems.

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.

For general teaching and learning spaces the occupied period is when students are in the space. For modelling purposes this is taken as from 09:00 to 16:00 and, excludes lunch periods and breaks.

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. See Section 2.5 below.

2.5 Ventilation of practical spaces

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. Ventilation in these spaces should be based on the minimum exhaust rates for pollutant control in Table 2.1. The minimum exhaust rate is as defined in ASHRAE 62-1.

Table 2.1 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	3.5

The rates 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[11] 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 rate by at least 25% either by the use of openable windows and doors or by boosting the exhaust at a higher noise level under override control of the teacher. This would allow 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 was reached. However, it is still necessary to achieve the minimum exhaust rates given in

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

Table 2.1 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 2.11.

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[12,13]. LEV is required in Science and Design and Technology practical spaces and preparation rooms and in some Art practical spaces.

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.

Exhausts from fume cupboards should discharge at a safe height above the highest part of the building. BS EN 14175 gives authoritative advice on the installation of fume cupboards and the discharge of fumes from buildings. Fume cupboard flues will normally need to terminate 3m above roof level, ie, outside the recirculation bubble. See further guidance on fume cupboards in EFA technical guidance on the ventilation of specialist spaces.

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

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

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 0 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 2.11.

2.6 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 on the ventilation of specialist spaces.

2.7 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.

Table 2.2 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. Cooling is also often required to reprographics machinery due to the high heat loads produced which cannot be dealt with by extract at this rate. Note that if operators are continuously in the room, use greater extract and whole-building ventilation rates
Sanitary accommodation and washrooms.	Intermittent air-extract rates of: • 25 l/s per shower head/bath; • 25 l/s per WC/urinal. These rates are higher than those given in ADF and are based on ASHRAE 62.1-2013 and ASHRAE 62.1 addenda, 2015.
Cleaners' stores.	Extract ventilation should be provided. This can be added onto toilet extract systems where they are nearby.
Food and beverage preparation areas (not commercial kitchens or food technology areas)	Intermittent air-extract rate of: • 15 l/s with microwave and beverages only; IGEM UP/11 guidance on gas safety should be consulted in preference to AD F for extract rates for gas cookers. See Section 2.11 below on the gas safety regulations. All to operate while food and beverages preparation is in progress.
Specialist rooms (e.g. commercial kitchens, fitness rooms, science labs, food-technology areas).	See Table 6.3 of Approved Document F1 and EFA technical guidance on ventilation of specialist spaces and local exhaust ventilation. Local exhaust ventilation includes fume cupboards and local exhaust-hood-type vent systems that remove pollutants at source.

Photocopiers have active carbon filters which, if well maintained, will limit ozone emissions. Information about the maintenance of photocopiers can be found in Local Authority Circular: LAC 90/2 [14].

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

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.

2.8 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 3 gives guidance on how to do this. Approved Document F (AD F) gives recommended performance levels for indoor air quality in office-type accommodation and this guidance should be met in schools. These performance levels agree with the World Health Organisation (WHO, 2010) indoor air quality guidelines. The WHO indoor air quality guidelines have been used as the basis of the DfE standards in this document as they are more up to date and comprehensive than the levels quoted in AD F. See Table 3.1 for an overview and comparison of the various pollutant threshold levels.

Where external air pollutants exceed the levels in National Air Quality Standards, consideration will need to be given to means of reducing pollutant levels in the indoor air. See Section 3.5.2 for filtration. This is especially important in Air Quality Management Areas[15] (where, by definition, external pollution levels of at least one pollutant have exceeded the Air Quality Standards) and in Low Emission Zones.

2.9 Location of ventilation air intakes and exhausts

It is important to ensure that the intake air is as uncontaminated as possible regardless of the type of ventilation system in operation.

The siting of exhausts, including chimneys, flues and fume cupboard discharge stacks is important.

2.10 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.

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

Design in accordance with Section 3.11 will reduce the risk of overheating and ensure compliance with the requirements of Part L of the Building Regulations and Workplace Regulation 7 to reduce summertime overheating.

2.11 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[16]. 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.

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.

The HSE/GasSafe (Health and Safety Executive) interpretation of the Gas Safety (Installation and Use) Regulations.

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.

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

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. CO2, 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.

2.11.1 Carbon monoxide detectors in schools

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[17] 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.

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[17] 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.

3 Indoor and outdoor air quality and thermal comfort

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.

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

WHO (WHO, 2010[18]) 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)[19] 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) [20].

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[18] 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

[19] 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/what-we-publish/abstracts/who-guidelines-for-indoorair-quality-dampness-and-mould

[20] 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 3.1 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 3.1 to align with the World Health Organisation (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 μg/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 3.1 WHO Indoor air quality guidelines and UK ambient air quality objectives

Pollutants	WHO Indoor Air Quality Guidelines(2010)[21]	UK Air Quality Objectives (DEFRA, 2007)[22]
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 (µg/m^3)	250 (1yr)	

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

[22] 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)[21]	UK Air Quality Objectives (DEFRA, 2007)[22]
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

3.2 Indoor air pollutants

In line with the above guidelines, the SINPHONIE project proposed and used the pollutants that are presented in Table 3.2, as indicators for IAQ.

Table 3.2 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 3.2 are discussed in the SINPHONIE guidelines for schools and are presented in Annex B.
In addition to Table 3.2 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 preparation areas and in science labs when gas cookers and 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 3.2. 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[23] and the DfE guidance on asbestos management for schools[24].

Radon – 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. 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.

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.

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

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

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[25].

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

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

Table 3.3.

Table 3.3 Typical sources of indoor air pollutants in school buildings

Outdoor sources	Building equipment, components & furnishings	Other potential indoor sources
Outdoor air pollution • Pollen, dust, mould spores • Industrial emissions • Vehicle emissions • Agriculture and farms • Outdoor machinery emissions	**HVAC equipment** • Mould growth in drip pans, ductwork, coils and humidifiers • Improper venting of combustion products • Dust or debris in plenums and ducts	• 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.
	Other equipment • Emissions from office equipment (volatile organic compounds, ozone) • Emissions from shop, lab and cleaning equipment	
Nearby sources • Loading bays • Odours from rubbish bins • Unsanitary debris or building exhausts near outdoor air intakes	**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	
Underground sources • Radon • Pesticides • Leakage from underground storage tanks	**Furnishings** • Emissions from new furnishings and floorings • Mould growth on or in soiled or water damaged furnishings	

3.4 Minimising sources

3.4.1 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[26] 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, within occupied areas, by ventilation, air conditioning or heating systems should be minimised. Similarly, 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.

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

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[27]. 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 Table 3.4) 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[28]). 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

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

[27] www.cleapss.org.uk

[28] 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.

be selected that have been shown to have good emission performance according to a scheme shown in Table 3.4.

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 (EN13986:2004, EN 14080:2005, EN 14342:2013, EN 14041:2006, EN 13964:2004).

Table 3.4 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 [29], and information on source control to minimise dust mite allergens is available in BRE Report BR 417 [30].

3.5 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 need to be considered include those covered by the UK National Air Quality Strategy (NAQS) (DETR, 2007)[31]. These are presented in Table 3.1. 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 as described in Table 3.5.

3.5.1 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.

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

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

[31] 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.

Internal contamination of buildings from outdoor pollution sources therefore depends upon:

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

Further information can be found in Kukadia and Hall (2004)[32].

The SINPHONIE guidelines[33] 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[34]. 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 3.1. It is therefore often necessary to consider the best means to ameliorate the effects of high levels of external pollution as part of the design of the ventilation of school buildings.

The draft EN 13779[35] 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.

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[32] 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

[33] 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

[34] Fuller G, Mittal L. Air Quality in London – briefing note to GLA Environment and Health Committee July 2012, King's College London.

[35] BS EN 13779 standard is currently under revision (See prEN 16798-3 and prCEN/TR 16981-4).

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

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

3.5.2 Filtration

Filtration provides a means of cleaning the intake air. It is standard practice to fit filters to mechanical ventilation systems. Standards for specification of filters are described in 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.

Filtration systems should be designed to deal with the 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 more costly and more 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 appropriately 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 filter dirty signal should be recorded on the BMS (building management system) or as a minimum a manometer should be fitted to the AHU (air handling unit).

Table 3.5 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

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.

BSEN13779:2007 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.

3.5.4 Location of ventilation air intakes

It is important to ensure that the 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 [36] where, by definition, pollution levels of at least one pollutant have exceeded the Air Quality Standards [37]. The siting of exhausts and fume cupboard discharge stacks is also important – this is discussed below.

Guidance on ventilation intake placement for minimising ingress of pollutants is summarised in Table 3.6 (reproduced from Approved Document F). The guidance given in Table 3.6 is greatly simplified and cannot be applied to all sites. The risks

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

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

associated with specific sites may need to be assessed by an expert[38] and may require use of physical modelling.

Table 3.6 Guidance on ventilation intake placement for minimising ingress of pollutants (Derived from Table 3.1 of Approved Document F)

Pollutant source	Recommendation
Local static sources: • Parking areas; • Welding areas; • Loading bays; • Adjacent building exhausts; • Stack discharges.	Ventilation intakes need to be placed away from the direct impact of short-range pollution sources, especially if the sources are within a few metres of the building. Guidance is given in CIBSE TM21[39] and ASHRAE 62-1, 2013. Consider the positioning of school parking and bus drop offs in relation to air intakes.
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. EN 13779 gives the standards that apply to the design of ventilation systems to reduce the ingress of external 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

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[38] ASHRAE 62-1 gives guidelines.

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

Pollutant source	Recommendation
	UK Air website. ASHRAE 62-1 gives guidance on positioning of intakes and extracts.
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 source in an open or well-ventilated area. Steps should also be taken to reduce the polluted source e.g. parking and loading should be avoided 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 the pollutants would be an obvious choice for locating ventilation intakes, but this may require expert assistance, such as numerical and wind-tunnel modelling. In general, however, it is recommended that the air intakes be positioned as far as possible from the source, at a location where air is free to move around the intake. ASHRAE 62-1 gives detailed guidance on positioning of intakes and extracts.
Weather factors	In areas where predominant wind comes from one 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.

3.5.4 Location of exhaust outlets

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

- Exhausts should be located downstream of intakes where there is a prevailing wind direction.
- Exhausts should discharge away from air conditioning condensers.
- To avoid unintentional recirculation location of mechanical exhausts should be carefully considered. For example, discharge into courtyards, enclosures or architectural screens may cause problems as pollutants do not disperse very readily in such spaces.
- It is recommended that stacks should discharge vertically upwards and at high level to clear surrounding buildings, and so that downwash does not occur.

Where possible, pollutants from mechanical extracts should 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. This effect only applies to mechanical ventilation discharges and not to natural ventilation outlets.

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 should be used to demonstrate the necessary separation of intake and exhaust air. In some cases, airflow rates will need to be increased to achieve an adequate supply of outdoor air.

3.5.5 Biomass boiler flues

The World Health Organisation has no lower acceptable safety limit for the key constituents of biomass combustion fumes. Storage of biomass poses risks to health from carbon dioxide and methane build up from decay of biomass and from dust. 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. Chimney height approval under the Clean Air Act is a separate consenting process from planning consent.

3.5.6 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. Full details on achieving and verifying performance are given in the ATTMA publication ‘Air Permeability Measurement’ [40].

All ventilation plant should be left in the closed position, ie, with dampers shut during the air permeability test. This includes natural ventilation louvres. Ventilation openings and ventilation plant should not be taped off for the air permeability tests. It is therefore advisable for manufacturers to test the air permeability of any dampers installed in the factory to eliminate manufacturing defects.

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

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.

3.6 Thermal comfort

Standards for all aspects of thermal comfort are set out in BS EN ISO 15251[41]. These are also the basis of the guidance in CIBSE Guide A, 2015. The Standards were derived from analyses of the perception of large groups of people to their surrounding environment. Their perception is influenced by many factors and is generally expressed in terms of whether they feel neither too hot nor too cold.

The main factors that influence thermal comfort are those which directly affect heat gain and loss and can be grouped in two categories: “environmental factors” which are conditions of the thermal environment, and “personal factors” which are

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[40] *Air Permeability Measurement*, Air tightness Testing and Measurement Association (ATTMA),

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

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.

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

Table 3.7 Categories of building

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

The EN 15251 categories are equivalent to and based on Categories A,B and C classifications of thermal environment in EN ISO 7730:2005 with the addition of a 4th category IV.

Table 3.8 below from EN 15251 shows how the categories relate to the PPD and PMV scores for overall thermal comfort.

Table 3.8 Category and PPD and PMV

Category	**Thermal state of the body as a whole**	
	PPD [%]	**Predicted Mean Vote [PMV]**
I	<6	-0.2<PMV<+0.2
II	<10	-0.5<PMV<+0.5
III	<15	-0.7<PMV<+0.7
IIII	<25	-1.0<PMV<+1.0

ASHRAE 55 2013 gives the PMV for acceptable comfort at the level of Category II for overall comfort and individual environmental criteria. This is a slightly higher level than the minimum acceptable standard chosen for schools of Category III and IV in some cases.

In some particular circumstances the standards quoted here for a particular category are higher or lower for schools. For example, for floor surface temperatures for underfloor heating a lower maximum temperature is quoted for each category. See Section 0 for further clarification.

Table 3.9, 3.10 and 3.11 below summarise how the comfort categories for schools relate to the specific environmental design criteria, which are further described in Sections 0 to 0.

Table 3.9 Comfort categories for schools for specific environmental criteria

	Vertical temperature difference (head-ankle)		Range of floor temperature		Radiant temperature assymetry				
Category of building	**PD**	**Temp Difference between 1.1 and 0.1m above the floor**	**PD**	**Floor surface temp range**	**PD**	**Warm ceiling***	**Cool wall**	**Cool ceiling**	**Warm wall**
	%	(°C)	%	(°C)	%	(°C)	(°C)	(°C)	(°C)
I	3	2	<6	23	5	<5	<10	<14	<23
II	5	3	<8	21 to 26	5	<5	<10	<14	<23
III	10	4	<10	19 to 29	10	<7	<12	<17	<35
IV	20	5	<15	17 to 31	20	<10	<15	<20	<45

* For ceiling heating, see Section 3.8 where Radiant Temperature Difference is defined which should meet the criteria given for Radiant Temperature Assymetry.

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 0 to 0 are based on: the adaptive thermal comfort standards for free running buildings outside the heating season; PD CR 1752:1999; ISO 7730; and EN 15251 with local interpretation for UK as described in CIBSE TM 52; and CIBSE Guide A.

The guidelines for thermal comfort in 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 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 a larger group of people within the same environment, and the PPD gives a quantitative measure of how many of these occupants will 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.

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.

3.7 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 within a limited range of air velocity and humidity. It is also a function of air velocity. This is one of a number of physical parameters used in a model of thermal comfort to determine discomfort.

Using the CIBSE equation for simple model heat losses, as detailed in CIBSE Guide A Section 5.6.2; 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 calculation method can be utilised to identify the interaction between air temperature and mean radiant temperature and how, when the radiant fraction of an emitter increases (for example if a convector type heater is replaced by a radiant type), and the operative temperature is controlled, the value of mean radiant temperature will rise and the air temperature will fall. As a result of increasing the mean radiant temperature within a space the air would not need to be heated to the same temperature to maintain the same operative temperature for thermal comfort.

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, and demonstrate by thermal modelling how typical and worst case scenarios rooms comply with the minimum and maximum operative temperature required, giving due consideration to the emitter type. Recommended operative temperatures in the heating season are listed in Table 3.10.The temperatures are for the heating season only. Temperature, ventilation and lighting controls in schools should be classroom based and simple to operate.

Table 3.10 Recommended operative temperatures during the heating season measured at 1.4m from the floor in the centre of the room

	Normal maintained operative temperature to be achieved by the heating system in less than 20 minutes after closing any external doors[42] - ^{0}C	Minimum maintained operative temperature provided by heating system during occupancy at the CIBSE outside design conditions - ^{0}C	Maximum operative temperature during the heating season at maximum occupancy - ^{0}C	Minimum recommended category for draught
Stores	5°C	N/A	N/A	N/A
Areas where there is a higher than normal level of physical activity (such as sports halls) and sleeping accommodation	17°C	15°C	23°C	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	17°C	15°C	24°C	Category IV
Kitchen preparation areas	20°C	15°C	N/A	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	19°C	25°C	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

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[42] This risk can be designed out by room layouts and the use of draught lobbies.

	Normal maintained operative temperature to be achieved by the heating system in less than 20 minutes after closing any external doors[42] - ^{0}C	**Minimum maintained operative temperature provided by heating system during occupancy at the CIBSE outside design conditions - ^{0}C**	**Maximum operative temperature during the heating season at maximum occupancy - ^{0}C**	**Minimum recommended category for draught**
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	19°C	26°C	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.	23°C	20°C	25°C	Category I or II
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	21°C in changing rooms and no more than 1^{0}C below that of the water temperature in pool halls	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	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.	25°C The air speed in these environments should be as low as possible and not exceed 0.15 m/s at 25°C	23°C	30°C	Category I

3.7.1 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.

The minimum recommended comfort categories for draughts are given in Table 3.10. Table 3.11 gives values for the maximum temperature difference between the room air and the temperature of the supply air plume and the maximum local air speed of the plume for the different comfort categories for schools.

Table 3.11 Recommended draught criteria to provide thermal comfort

Category of space/activity	Draught criteria to provide thermal comfort			
	Winter		Summer and mid-season	
	ΔT (Min maintained operative temp - plume local air temp)	Maximum air velocity (m/s)	ΔT ($T_{room, operative}$ - 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 3.11 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 air temperature as in Table 3.10 in winter and mid-season and 23°C in summer.

The values in Table 3.11 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.
Category IV should only be used in classrooms and other teaching spaces where there is local manual control over the ventilation rate eg manually opened windows

or room ventilation with variable speed control. However, the air quality criteria regarding CO_2 levels must still be met.

Higher speeds 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 can be used to predict the speeds and they can be measured with an anemometer. Air velocity should be measured with an omni-directional anemometer with a 0.2s time constant.

Air speeds from manually opened windows can exceed these figures under certain weather conditions but as they are directly controllable by the teacher this is permitted. However, the design air speed under average wind speed and buoyancy conditions should not exceed the Category IV figures. Where average wind speeds are not known a figure of 4.5m/s can be used.

For modelling purposes to determine the required size of summertime natural ventilation openings, the maximum average air speed to prevent summertime overheating should be less than 0.7m/s.

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 3.11 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.

The line plume calculator[43] 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.

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

3.8 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, un-insulated 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 rooms incorporating overhead radiant panels the designer should undertake calculations to determine the RTA within each space. In addition it is recommended to assess the plane radiant temperature increase in an upwards direction $\Delta T_{pr,}$ at the selected working head height. BS 7726 gives a method of measuring $\Delta T_{pr\,,}$in the 6 different directions in a room: 4 horizontal, upwards and downwards directions.

The head is the most sensitive part of the body for human thermos-regulation. It is therefore recommended to assess $\Delta T_{pr,,\ upwards}$ (difference in plane radiant temperature in the upwards direction) at normal head height due to the presence of a heating panel overhead. Seated head height is 1.1m above finished floor level (AFL) (for primary age children) or 1.4m AFL (for secondary students and adults) above the finished floor level. Seated head height should be used in classrooms and similar spaces where pupils are normally seated. Standing head height, 1.4m AFL (for primary age children) and 1.8m (for secondary students and adults) should be used in rooms where activities are normally standing up, e.g. halls, gyms and dance studios.

$\Delta T_{pr,,\ upwards}$ can be assessed directly below a radiant panel or an array of panels using the formulae in BS7726.

Radiant temperature asymmetry is defined in ISO 7730 as the difference between the Plane Radiant Temperatures measured in the upwards and downwards directions and according to BS7726 should be assessed at 0.6m AFL. It is an indication of the effect on body core temperature of the asymmetry between floor and ceiling.

It is recommended that as well as meeting the RTA at 0.6m AFL for the Category of building; that the ΔT_{pr} at head height due to the presence of the radiant panel overhead should not exceed 10K.

This is particularly important when there is a sedentary occupation such as people sitting at a desk. The requirements are dependent upon the defined room Category that will vary where pupils have special needs. Therefore, the designer should be aware of the standard to be achieved within the design. Where there are vulnerable pupils, e.g., those with low mobility or difficulty in thermoregulation, the RTA and ΔT_{pr} should be reduced.

It is acceptable for the temperature differences to be exceeded during morning boost and for a short recovery period of up to 20 minutes after outside doors are closed.

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 and ΔT_{pr} 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 and ΔT_{pr} resulting from offsetting the radiant panels. The option of integrating luminaires and acoustic absorbers within radiant panels should be considered.

Hot water radiators[44] 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.

Radiant temperature differences should be assessed for typical spaces using the formulae given in BS 7266.

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

3.9 Vertical temperature difference

Air temperatures generally increase from floor to ceiling level. 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.

3.10 Hot or cold feet caused by floor temperature

A floor that is too warm or too cold 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 above 17° and 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 23°C to 24°C maximum surface temperature with a supplementary heating system.

Note that in sports halls where radiant heating is used, then the floor temperature can be below 17°C and this would be uncomfortable unless shoes and socks are worn. The school should be consulted on the likely range of activities and a means to raise the floor temperature depending on the activity may be required.

Under-floor heating should not be used in large areas that may be covered with mats (e.g. in SEN rooms), or where regular spillages occur (for hygiene and odour control) 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).

3.11 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. 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 most relevant weather files from CIBSE's Design Summer Years[45].

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.

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

As a general rule, 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.

CIBSE has published criteria in TM52 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. Free running buildings are defined as those that are not mechanically cooled or heated. Most schools are free running outside the heating season.

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_{rm}, 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 3.12.

Table 3.12 Adaptive thermal comfort category to apply (as defined in Table 3.13)

Type of space/activity	New Build	Refurbishment
Teaching and learning, drama, dance, exams	II	III/IV
Practical activities such as cooking	N/A	N/A
Sports Halls	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.

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 3.13 below, as follows:

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

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

Therefore, for category II as defined in Table 3.13, below, where the acceptable range is 3^{0}C:

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

Table 3.13 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 °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 °C
II	Normal expectation	± 3 °C
III	An acceptable moderate level of expectation	± 4 °C
IV	Low level of expectation. This category should only be accepted for a limited part of the year	>4 °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

- $\Delta T = T_{op} - T_{max}$ (°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. The three criteria are:

- the number of hours for which an adaptive thermal comfort threshold temperature is exceeded
- the degree to which the operative temperature exceeds the adaptive thermal comfort threshold temperature
- the maximum temperature experienced at any occupied time.

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.

The building should be deemed to be overheating if any two of the three criteria are exceeded.

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 15W/m² or practical spaces where the equipment gains are less than 25W/m², as practical spaces are larger and have a lower occupancy gain per square metre than general teaching spaces. Some practical spaces have high heat loads, e.g. chemistry due to Bunsen burners; and graphics studios and music studios, which have large numbers of high-end computers.

3.12 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 to assess thermal comfort in buildings in use as these are easier for the occupants and facilities management team to understand. 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 as part of soft landings.

3.12.1 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[46] (lowest temperature from the previous night to the maximum daytime temperature the following day) is less than 4ºC.
- 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

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[46] 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.

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 they feel a space is too hot. 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).

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, proximity of noise and pollution sources, 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. Likewise, in certain polluted environments 100% mechanical ventilation including filtration is required. In most other cases in a school the most suitable system is a hybrid system or mixed mode system including a combination of natural, mixing and/or mechanical ventilation.

4.2 Natural ventilation

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

Single sided ventilation relies exclusively on openings on one side of the room creating a limiting depth for the room (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 depth of the room (typically 15m or 5 times the room height).

The minimum amount of effective area of ventilation openings that is required to provide comfort conditions should be calculated using dynamic thermal modelling. See Section 0.

To achieve cross ventilation, large openable areas are needed on opposite sides of the space of similar area. 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 and TM57 Ventilation Chapter.

4.2.1 Design of natural ventilation openings

For a natural ventilation system to provide adequate conditions 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.

High and low level openings can provide sufficient ventilation area together with a means of reducing draughts in the occupied zone by directing the airflow above the occupied zone under windy conditions. The high-level openings when combined with low level openings or cross ventilation are also better able to cool the thermal mass of the soffit if present.

4.2.2 Design of stack ventilation and atria

If a building is comprised of an atrium or circulation space then the buoyancy effect that arises when there is a temperature difference between the inside and outside is greater as the space height increases; this provides the potential to ventilate the building even when there is no wind.

Cross flow, stack ventilation via an atrium or stack is therefore very useful for preventing overheating in schools

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 are restricted. Simple models of atria design have therefore been developed to help at the design stage and prevent conceptual design errors[47].

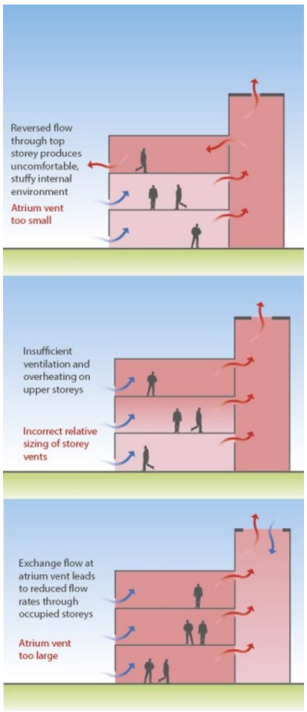

Figure 4.1 Examples of problematic flow patterns in a three storey atrium building

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[47] A Acred ‘Back to Basics’, CIBSE Journal September 2015;

The following guidelines have also 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:

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

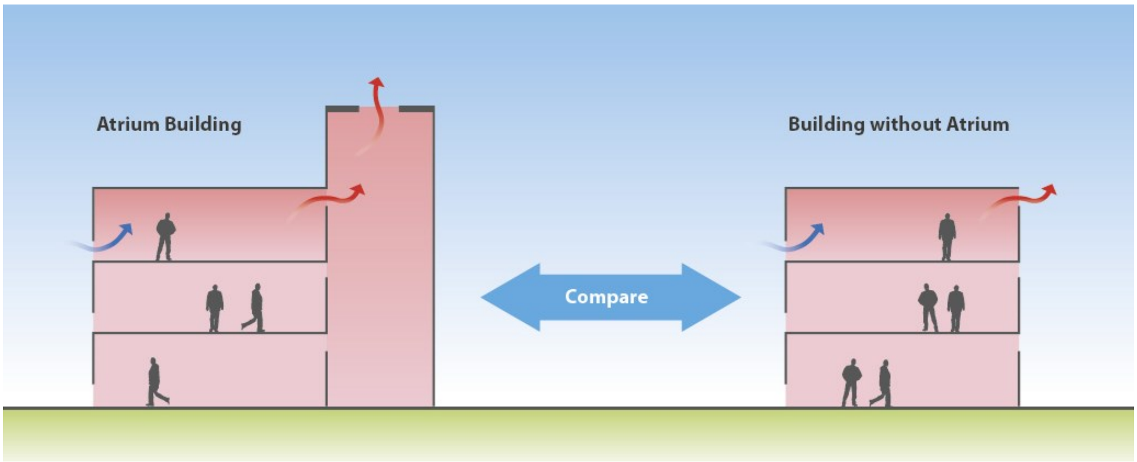

Figure 4.2 Definition of the atrium enhancement metric

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

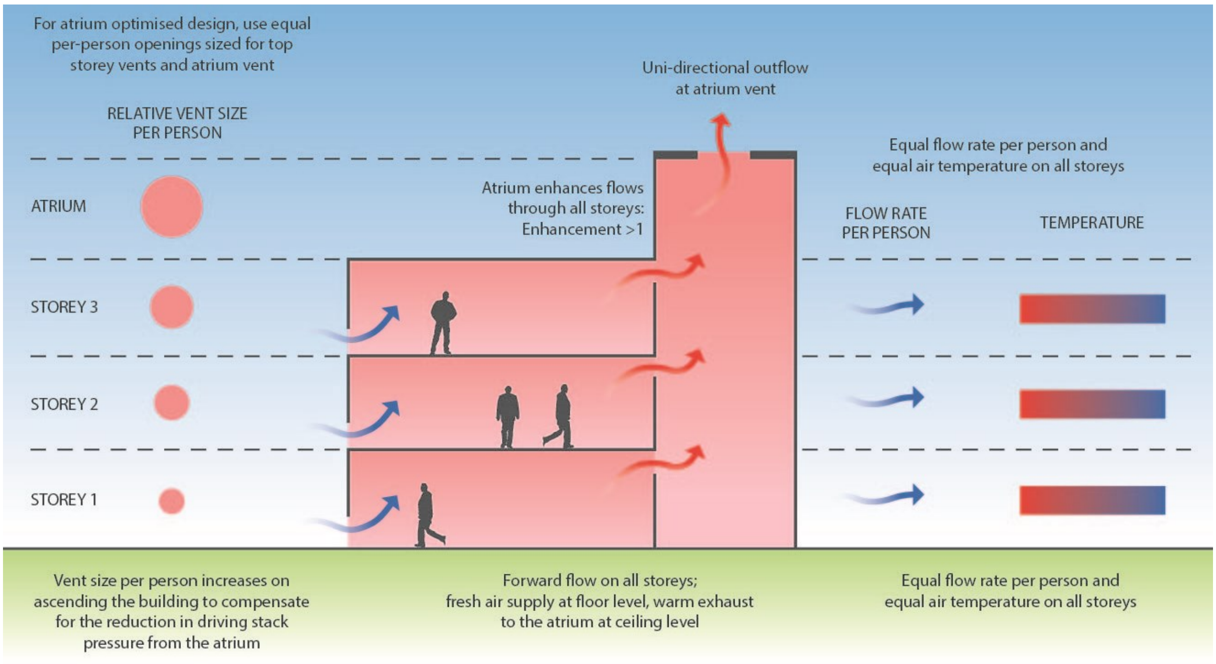

Figure 4.3 Ideal design blueprint for an atrium building.

4.3 Mechanical ventilation

Mechanical ventilation takes places 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 is high.

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

Mixing ventilation systems provide heat reuse within the space and 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 relatively small.

In older buildings being refurbished, the balance point can be as high as 15^{o}C 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 15°C. However, this is only possible if the airtightness is improved during the refurbishment, otherwise the MVHR will not be effective.

4.4 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 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 are 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 speeds.

4.5 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.

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 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 and simple users' guides should be provided.

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.

This should be carried out as part of handover and soft landings.

4.6 Control of cold draughts

When the outside air temperature is cold it will cause discomfort if the incoming air does not mix sufficiently with the room air before it reaches the occupied zone. As cold outside air is denser than the room air it will drop down onto the occupants. There is a limit below which incoming air 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 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. See Section 3.7.1 and the Line Plume Calculator.

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 under floor 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.

4.7 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). This may require the use of pressure relief systems or door opening mechanisms to ensure that doors can be opened by the users of the building.

A timed over-ride should be provided to allow teachers to shut off room-based ventilation systems temporarily in extreme wind conditions if these could cause back draught through the system, excessive noise or difficulty in opening doors.

4.7.1 Testing of dampers and weather louvres

Air leakage of dampers and thermal performance should be tested in accordance with BS EN 1751: 2014.[48]

External weather louvres should be provided to the appropriate weather and air flow ratings to prevent rain penetration as defined by BS 13030:2001[49].

4.8 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 and door design is covered in detail in EFA technical guidance on external fabric design.

4.9 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

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[48] BS EN 1751:2014 Ventilation for buildings. Air terminal devices. Aerodynamic testing of damper and valves

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

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 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 through use of thermal mass. The design should also prevent a layer of hot air being trapped at ceiling level in summertime leading to high temperatures at ceiling level.

A simple way to achieve this is to provide sufficient high-level free opening area, e.g., at least 1.5% of the floor area, the top of which is within 200mm of ceiling level. This will significantly reduce the risk of summertime overheating of the room and excess asymmetric radiation from a warm ceiling.

Walls and floors can also 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. Plasterboard can provide useful thermal mass. 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. For example, plasterboard densities typically range from 650 to 1150 Kg/m^3.

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.

High-level vents should be as close as possible to the soffit, which can complement the need to get window heads as high as possible for good daylighting. This is to prevent a layer of hot air being trapped at ceiling level in summertime leading to high temperatures at ceiling level.

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.

4.9.1 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. Fans used for night purge should therefore have as low a specific fan power in night purge mode as possible, preferably less than or equal to the specific fan power for the fans in daytime mode.

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 should be considered, e.g., nuisance tripping due to insects or movement of blinds.

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 and over-estimating the benefit of the night purge strategy.

4.10 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. MVHR systems should have a minimum heat recovery efficiency factor of 75%, measured in accordance with EN 308. 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 ensure air quality even when windows are closed.

See EFA technical guidance on building services design and CIBSE TM57.

4.11 Climate change adaptation

The future proofing of the indoor environment of teaching spaces is important. The use of the EN 15251 adaptive thermal comfort criteria instead of the temperature threshold of 28^{o}C 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, e.g., 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[50]. Whilst atria can be useful, great care should be taken to avoid overheating which is a significant risk if atria are over-

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[50] “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.

glazed with large horizontal glazed areas 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 required 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.

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/

4.12 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 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. Allowance should be made for the metabolic and equipment heat gains when the school is occupied to prevent over-sizing. These gains normally provide sufficient heat to warm the incoming ventilation air without additional heating for much of the year, as long as the incoming air is adequately mixed with room air to mitigate cold draughts.

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.

4.13 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 should be fitted with filter alarms e.g., differential pressure sensors or hours run since last filter change and should 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 should 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. The set points for control of ventilation are as important as the maximum design target for (CO_2).

Control set points for the ventilation system supplying teaching spaces in schools (which can include opening windows when appropriate) should be set so that the annual average level over the occupied period does not exceed 1000ppm.

4.14 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.

4.14.1 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 Design calculations

Ventilation and thermal comfort design for teaching and learning activities should be proved by modelling for the occupied period and internal conditions described in Section 0. 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.

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 ventilators. See Section 5.5.

5.1 Weather File

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

The most up to date and appropriate CIBSE DSY should 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.

5.2 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 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.

The design of mechanical ventilation should meet the minimum standard of the "Non Domestic building Service Compliance Guide" [51] and heat recovery should be considered.

5.3 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 and small power sets back to 50% of the peak loads during lunch hour (typically 12:00-13:00) in all areas, lighting stays constant
- The school is assumed to be occupied throughout the summer period for modelling of overheating. (This provides a degree of future proofing.)

5.4 Internal gains

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.

Lighting gains in classrooms should be considered to be 10 W/m^2 unless calculations e.g. of daylight displacement show 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

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[51] Non Domestic building Service Compliance Guide

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 15 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.

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.

5.5 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[52].

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 manufacturers.

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

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[52] *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.

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

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

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.

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.

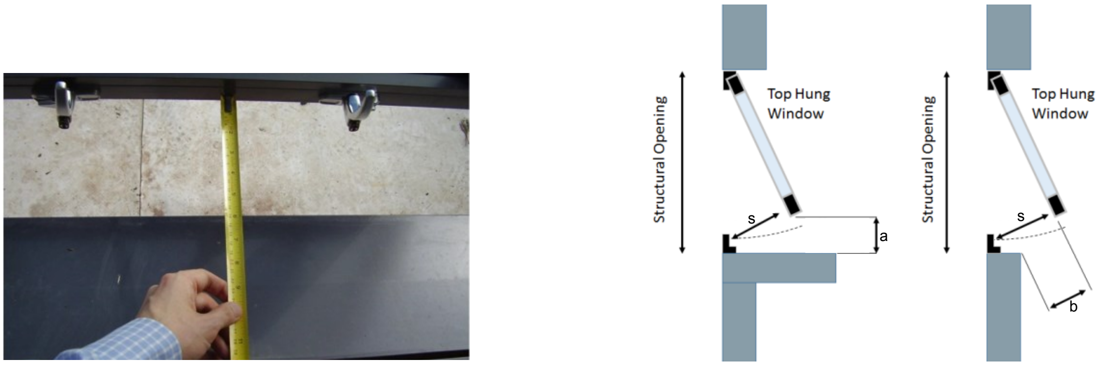

Figure 5.1 Example of ventilation area reduced by the protrusion of the window sill. In the example above top hung windows are opened by the same stroke length, s, but the protruding sill impacts on the free area because a<b

Figure 5.2 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.

The lowest ventilation rate of 8 l/s/person for schools is also proposed by the results of the HealthVent project[53]. 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^oC or 22^oC 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[54]. 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 0 correspond to category II for ventilation with an allowance for category III for part of the time for natural and hybrid ventilation solutions.

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.

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

[54] 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;

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.

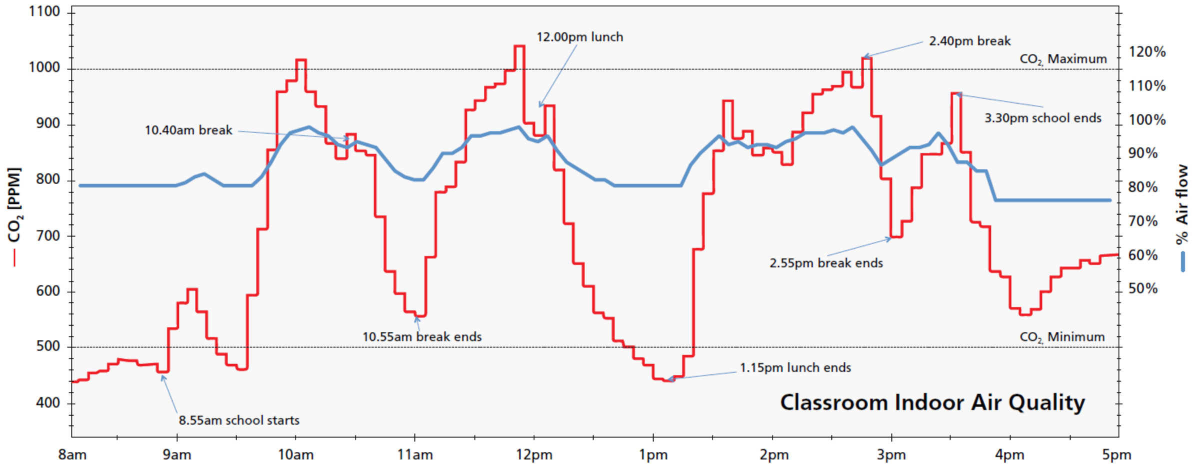

Figure A.1 Typical changes in CO2 levels with demand controlled room-based mechanical ventilation systems, Graph provided by SAV Airmaster

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.

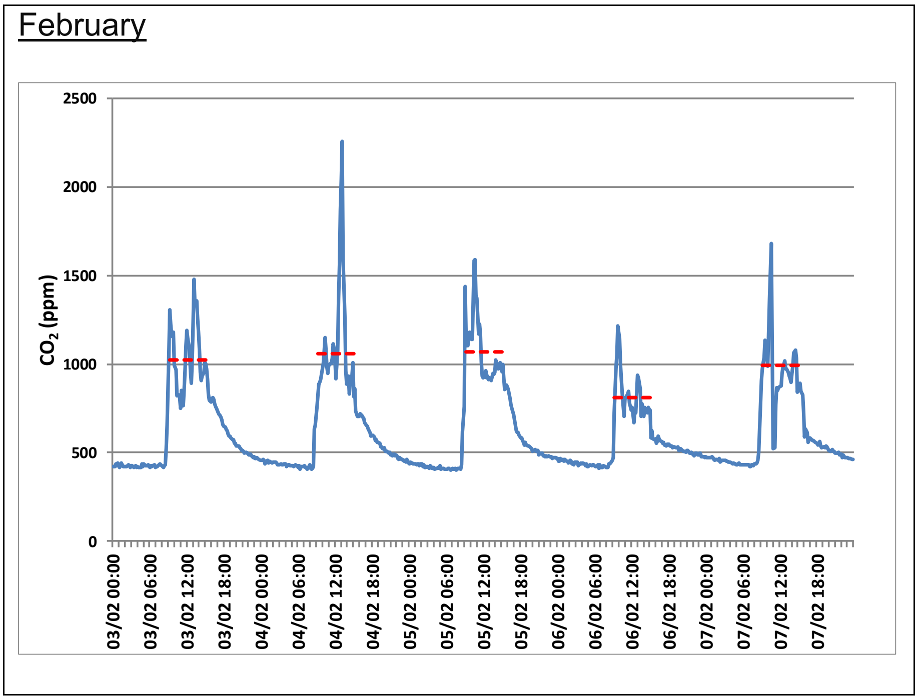

Figure A.2 Average occupied CO_2 concentration in February, for a secondary maths classroom in a school in the North West of England. Graphs provided by SE Controls

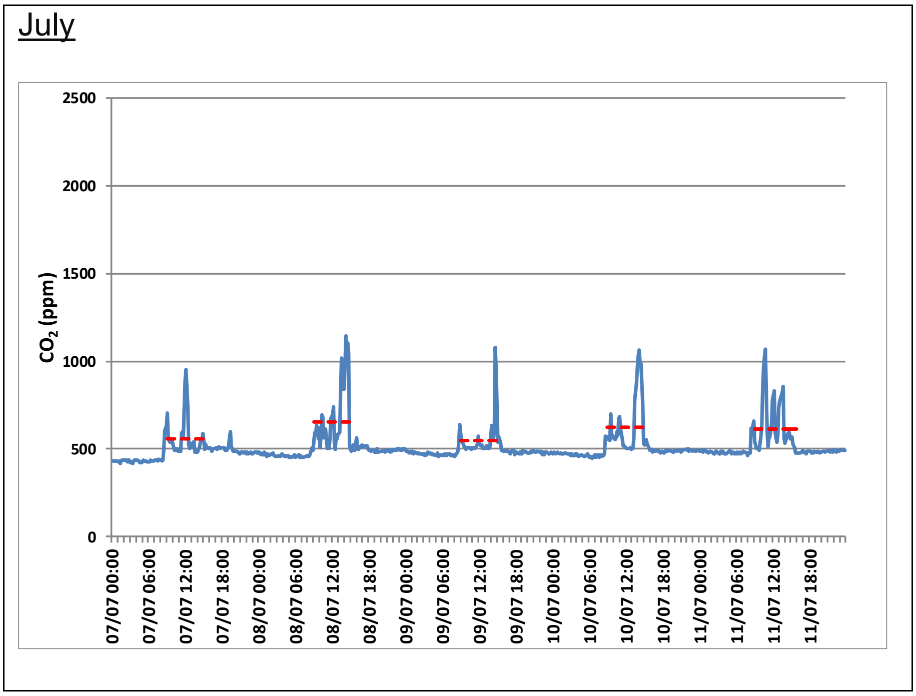

Figure A.3 Average occupied CO_2 concentration in July, for a secondary maths classroom in a school in the North West of England. Graphs provided by SE Controls

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.

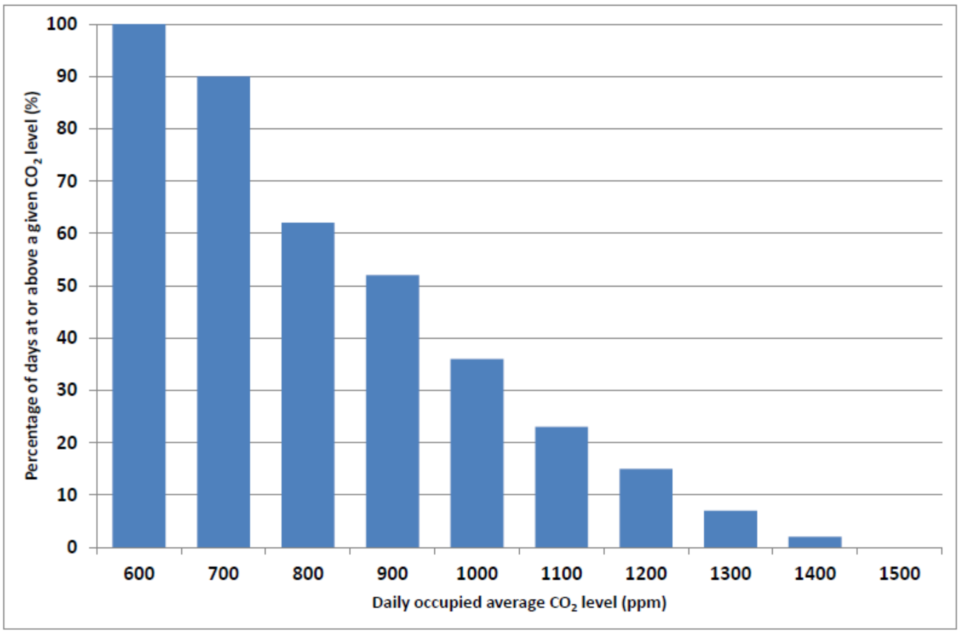

Figure A.4 A Secondary School all year CO2 monitored results. Graph provided by Breathing Buildings

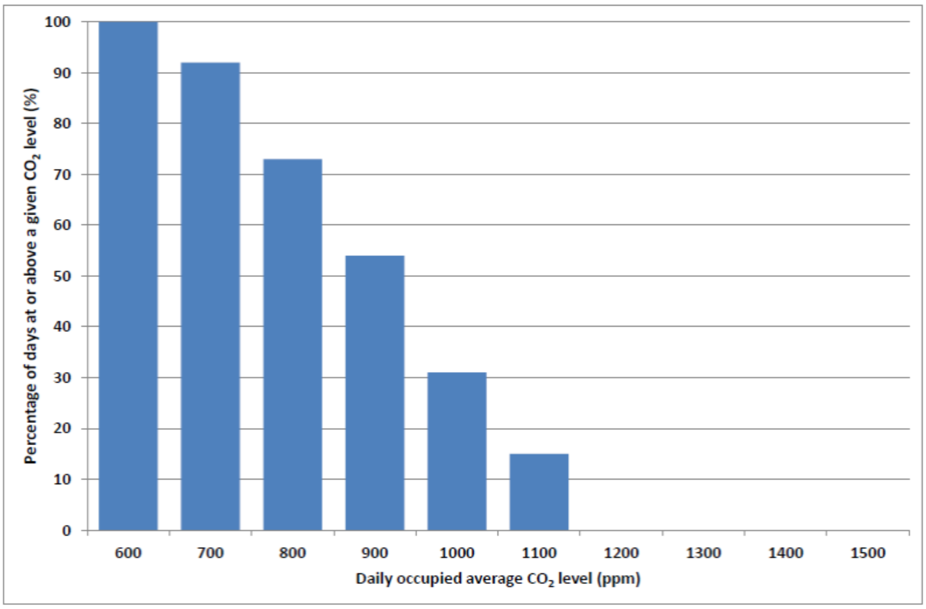

Figure A.5 A Preparatory School for age up to 13 years wintertime CO2 levels monitored. Graph provided by Breathing Buildings

The graphs above show that mechanical, natural and hybrid ventilation systems can all achieve good standards of ventilation over the year.

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[55]

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

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[55] 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.
Tetrachloroethylene	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.

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