Heating, ventilating, air conditioning and refrigeration

CIBSE Guide B

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Department of Trade and Industry

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Table 2.9 Summary of recommendations

Building sector	Section number	Recommendation
Animal husbandry	2.3.24.1	See Table 2.28
Assembly halls	2.3.3	See Table 2.14
Atria	2.3.4	See section 2.3.4.3
Broadcasting studios	2.3.5	6–10 ACH (but heat gain should be assessed)
Call centres	2.3.24.2	4–6 ACH (but heat gain should be assessed)
Catering (inc. commercial kitchens)	2.3.6	30–40 ACH
Cleanrooms	2.3.7	See Tables 2.19 and 2.20
Communal residential buildings	2.3.8	0.5–1 ACH
Computer rooms	2.3.9	See Table 2.21
Court rooms	2.3.24.3	As for typical naturally ventilated buildings
Darkrooms (photographic)	2.3.24.4	6–8 ACH (but heat gain should be assessed)
Dealing rooms	2.3.24.5	As offices for ventilation (but heat gain should be assessed)
Dwellings (inc. high-rise dwellings)	2.3.10	0.5–1 ACH
Factories and warehouses	2.3.11	See 2.3.11.1 for regulatory requirements
High-rise (non-domestic) buildings	2.3.12	4–6 ACH for office areas; up to 10 ACH for meeting spaces
Horticulture	2.3.24.6	30–50 litre·s^{-1}·m^{-2} for greenhouses (45–60 ACH)
Hospitals and health care buildings	2.3.13	See Table 2.23
Hotels	2.3.14	10–15 ACH minimum for guest rooms with en-suite bathrooms
Industrial ventilation	2.3.15	Sufficient to minimise airborne contamination
Laboratories	2.3.16	6-15 ACH (allowance must be made for fume cupboards)
Museums, libraries and art galleries	2.3.17	Depends on nature of exhibits
Offices	2.3.2	See Tables 2.10 and 2.11
Plant rooms	2.3.18	Specific regulations apply, see section 2.3.18
Schools and educational buildings	2.3.19	See Table 2.26
Shops and retail premises	2.3.20	5–8 litre·s^{-1} per person
Sports centres (inc. swimming pools)	2.3.21	See Table 2.27
Standards rooms	2.3.24.7	45–60 ACH
Toilets	2.3.22	Building Regulations apply; opening windows of area 1/20th. of floor area or mechanical ventilation at 6 litre·s^{-1} per WC or 3 ACH minimum for non-domestic buildings; opening windows of area 1/20th. of floor area (1/30th. in Scotland) or mechanical extract at 6 litre·s^{-1} (3 ACH in Scotland) minimum for dwellings
Transportation buildings (inc. car parks)	2.3.23	6 ACH for car parks (normal operation) 10 ACH (fire conditions)

— Approved Document J: *Heat producing appliances*[38]

— Approved Document B: *Fire safety*[39]

— Approved Document L: *Conservation of fuel and power*[1]

Note that if dilution is the main basis of control then the ventilation system should be designed to produce good mixing of the incoming air with the contaminant within the space. In situations where the contaminant release is from a fixed source then it is preferable to arrange the extract location as close to the source as possible so that direct removal is achieved. Requirements will also be affected by the ventilation efficiency, i.e. whether all the fresh air supplied is used or whether some is extracted prematurely. See section 2.4.2.2 for further consideration.

Section 1 of CIBSE Guide A: *Environmental design*[12] should be consulted for the definition of, and requirements for achieving, suitable indoor air quality standards. It describes two methods for determining suitable outdoor air ventilation rates:

— a prescriptive method

— a calculation method for the control of a single known pollutant being released at a known rate.

These are summarised below. A third method has been suggested[7,8] for use where pollution sources are known but not their emission rates or limiting concentrations

(*a*) Prescribed outdoor air supply rate

The prescriptive method is based on chamber studies where tobacco smoke and body odour were considered to be the only pollutant sources. This may result in an underestimate of requirements if other pollutants are present.

(*b*) Calculation method for control of a specific pollutant

Where a single known pollutant is being release at a known rate the calculation is based on risk assessments under the Control of Substances Hazardous to Health (COSHH) Regulations.[42] The Health and Safety Executive (HSE) publishes annual guidance[43] on the limits to which exposure to hazardous airborne substances should be controlled in workplaces. This is in the form of occupational exposure limits (OELs) for long-term (8 hour) and short-term (10 minute) exposures. OELs are available for a large number of substances. While these concentration limits must not be exceeded, it is recommended that exposure should be kept as low as is reasonably practical. Compliance with these limits is a fundamental requirement of the COSHH Regulations.

For situations where exposure may be longer than 8 hours a day, or where more susceptible members of the general population, such as the elderly, the young and those prone to ill-health, are involved values lower than the OELS should be applied. It has been suggested that one fifth of the OEL might be an acceptable standard, although limited information is available. Further guidance on pollutant levels for the general population is also available from the World Health Organisation[44].

For a single contaminant under steady conditions, equation 2.1 may be applied to determine the flow of outdoor air that, with good mixing, would maintain the contaminant concentration at a specified level.

$$Q = \frac{q\,(10^6 - C_i)}{(C_i - C_o)} \tag{2.1}$$

where Q is the outdoor air supply rate (litre·s^{-1}), q is the pollutant emission rate (litre·s^{-1}), C_o is the concentration of pollutant in the outdoor air (ppm) and C_i is the limit of concentration of pollutant in the indoor air (ppm).

This equation can be adapted for:

— pollutant thresholds quoted in mg·m^{-3} and situations where C_i is small or the incoming air is free of the pollutant in question, see CIBSE Guide A[12], section 1.7.3.1

— situations where the ventilation results in a non-uniform concentration so that a higher than average concentrations exist in the occupied zone and the outdoor air supply rate requires to be increased, see CIBSE Guide A, sections 1.7.3.1 and 1.7.4

— non-steady state conditions that might allow the outdoor air supply rate to be reduced, see CIBSE Guide A, section 1.7.3.2.

A more comprehensive analysis of the relationship between contaminant concentration and ventilation rate is given in BS 5925[45].

Note that the existing guidelines for the calculations of outside air ventilation rates are based on the assumptions that the air outside the building is 'fresh' and that the pollutant load is inside the building. For buildings in city areas or adjacent to busy roads the quality of the outside air needs to be assessed, as this can also be a source of pollutants. Where specific problems are anticipated, an air quality survey should be undertaken. This should include measurements at likely times of peak pollution.

The use of natural ventilation means that it is much more difficult to clean the air entering the building. Mechanical ventilation and air conditioning systems can filter the incoming air to remove dust and dirt, but only specialised air treatment can remove gaseous pollutants (e.g. oxides of carbon and nitrogen from traffic fumes). In all building types, gaseous pollutants can be minimised by careful siting of ventilation inlets, see section 2.4.3 and CIBSE TM 21[28].

In mechanically ventilated buildings, effective air filtration relies on good maintenance[46]. Poor filtration performance can allow dirt and dust to accumulate within a ductwork system, reducing the efficiency of heat exchange equipment and providing potential sites for microbiological activity. Spores and bacteria can then be released into the occupied space, causing potential comfort and health problems. Natural ventilation systems, on the other hand, are generally more accessible for cleaning and maintenance, and there are no components subject to high humidity, such as cooling coils, or humidifiers, which can harbour biological growth.

As well as assessing external air quality, the sources of internal pollution should also be reviewed so that their effect can be minimised or even eliminated. Ventilation should not be used in place of source control to minimise pollutant concentrations in a space.

(*c*) Calculation method for control of multiple pollutants

There is no accepted approach for the derivation of exposure limits for mixtures of contaminants, although some guidance is given in EH40[43]. In such cases it is recommended that specialist assistance be sought from occupational hygienists or toxicologists. Likewise, guidance currently only exists for a small number of substances in terms of acceptable limits to avoid sensory, as opposed to health, effects[44]. In practice, the exposure of workers in non-industrial environments to these same concentrations of contaminants would not be acceptable and a multiplying factor of 0.1 has been suggested.

A method to deal with the dilution of pollution from non-human sources has been suggested[40,41], see equation 2.2:

$$Q_c = \frac{10\,G}{E_v\,(P_i - P_o)} \tag{2.2}$$

where Q_c is the outdoor air supply rate to account for the total contaminant load (litre·s^{-1}), G is the sensory pollution load (olf), E_v is the ventilation effectiveness, P_i is the design perceived indoor air quality (decipol) and P_o is the perceived outdoor air quality (decipol). These units are defined elsewhere[40,41].

However, this proposal is still subject to discussion and has not yet gained international acceptance.

Human respiration

Carbon dioxide is a dense odourless gas produced by combustion and respiration. The rate of ventilation required for the supply of oxygen for breathing is far outweighed by any requirement for the dilution of exhaled carbon dioxide (CO_2). A build-up of this gas in a room leads to a feeling of stuffiness and can impair concentration. Elevated levels of CO_2 in the body cause an increase in the rate of respiration. Slightly deeper breathing begins to occur when the atmospheric concentration exceeds 9000 $mg \cdot m^{-3}$ or 5000 ppm (0.5% by volume). This is the maximum allowable concentration of CO_2 for 8-hour exposures by healthy adults(43). In the USA, one half of this limit (0.25%) has been taken as appropriate for general building environments(47).

These figures are based on sedentary occupations; minimum ventilation rates for various activity levels to prevent these limits being exceeded are given in Table 2.10.

For most applications involving human occupancy, the CO_2 limits shown in Table 2.10 are not usually taken as a design criterion as much more air needs to be provided to meet criteria such as the dilution of odours or tobacco smoke.

Within the UK, a CO_2 figure of 800–1000 ppm is often used as an indicator that the ventilation rate in a building is adequate. One thousand parts per million would appear to equate to a 'fresh air' ventilation rate of about 8 $litre \cdot s^{-1}$ per person. In Sweden, the equivalent indicator is 1000 ppm, with a desired level of 600–800 ppm. Note that as outside air itself contains carbon dioxide (approx. 350 ppm), a 50% reduction in internal levels from 1600 ppm to 800 ppm requires a four-fold increase in ventilation rate.

Table 2.10 Ventilation rates required to limit CO_2 concentration for differing activity levels

Activity	Minimum ventilation requirement / ($litre \cdot s^{-1}$ per person)	
	0.5% CO_2 limit	0.25% CO_2 limit
Seated quietly	0.8	1.8
Light work	1.3–2.6	2.8–5.6
Moderate work	2.6–3.9	N/A
Heavy work	3.9–5.3	N/A
Very heavy work	5.3–6.4	N/A

Body odour

The ventilation rate required depends on whether the criterion is (*a*) acceptability to the occupants or (*b*) acceptability to visitors entering the occupied space. In studies on auditoria(48), it was found that that the occupants themselves were insensitive to changes in ventilation over the range 5–15 $litre \cdot s^{-1}$ per person, although there were always nearly 10% of the occupants dissatisfied with the odour level.

Similarly, it has been shown that an outdoor flow rate of 7 to 8 $litre \cdot s^{-1}$ per person is required to restrict the level of body odour so that no more than 20% of the entrants to the occupied space were dissatisfied. The sensitivity was such that halving the ventilation rate increased the proportion dissatisfied to 30%, while more than three times the ventilation rate was required before the proportion decreased to 10%.

Therefore in the absence of further information, it is recommended that 8 $litre \cdot s^{-1}$ per person should be taken as the minimum ventilation rate to control body odour levels in rooms with sedentary occupants. There is evidently a relationship between CO_2 concentration and body odour intensity in occupied rooms. Thus for intermittent or varying occupancy, the control of ventilation rates by CO_2 concentration monitoring can be effective in matching the supply of air supply to the changing requirements.

Tobacco smoke

The suggested outdoor air supply rate of 8 $litre \cdot s^{-1}$ is based on sedentary occupants and the absence of any other requirements, e.g. the removal of moisture. This is consistent with the requirements for the removal of body odour but assumes the absence of any smoking. There are no definitive criteria for the required dilution of tobacco smoke. Uncertainties relate particularly to the respirable particulate component (see page 2-16). Evidence suggests that particle removal by filtration is necessary to avoid excessively high ventilation rates.

Smoking also produces undesirable odours, particularly to non-smokers. One study(49) has shown that filtration of the smoke particles did not alleviate the odour nuisance, indicating that much higher rates of ventilation are now required to avoid dissatisfaction of more than 20% of visitors to a room occupied by cigarette smokers. Ventilation rates for smokers of 4 or 5 times that required for non-smokers have been suggested although, allowing for the fact that a minority of the occupants may be smokers, the overall ventilation rate may be only twice that needed for non-smoking situations.

If smoking is prohibited, then the rate for 'no smoking' may be used, see Table 2.11. For the other situations described in the table, it has been assumed that each smoker present consumes an average of 1.3 cigarettes per hour. It should be noted that, regardless of the ventilation rate used, the health risks of cigarette smoke cannot be completely eliminated. It is recommended that designers consult current guidelines, such as those issued by the Health and Safety Executive(50), and ensure that clients are made aware of any risks involved in the chosen design strategy. Legal advice may also be advisable.

Table 2.11 Recommended outdoor air supply rates for sedentary occupants(6)

Level of smoking	Proportion of occupants that smoke / %	Outdoor air supply rate / ($litre \cdot s^{-1}$ per person)
No smoking	0	8
Some smoking	25	16
Heavy smoking	45	24
Very heavy smoking	75	36

Volatile organic compounds (vocs)

VOCs cover a wide range of compounds having boiling points in the range of 50–260 °C and hence existing in vapour form at room temperature. They are particularly prevalent in new and recently refurbished buildings, coming from a variety of sources including:

- people, animals, plants
- consumer products (cleaning agents, paints, glues, solvents etc.)
- building materials and treatment (damp-proofing, furnishings etc.)
- building services and other equipment
- outdoor air.

Analysis is normally restricted to measuring the total VOC content in air. ASHRAE Standard 62[51] suggests that complaints are unlikely to arise for total VOC concentrations below 300 $mg \cdot m^{-3}$, whereas above 3000 $mg \cdot m^{-3}$ complaints are likely. Details of the appropriate ventilation provision can be found in section 1 of CIBSE Guide A[12].

Respirable particles (PM_{10})

Respirable particles are those constituents of the air that are not in purely gaseous form. They can be ingested into the lungs while breathing and cause a wide range of health problems. The most potentially dangerous particulates are asbestos fibres but there are concerns about other 'man-made mineral fibres' (MMMF) which are widely used for insulation within buildings. Particulate matter is monitored in the UK as PM_{10}, i.e. particles generally less than 10 microns in diameter. A large number of epidemiological studies have shown that day-to-day variations in concentrations of particles are associated with adverse effects on health from heart and lung disorders, and a worsening of the condition of those with asthma. Details of the appropriate ventilation provision can be found in section 1 of CIBSE Guide A[12].

Radon

Radon is a colourless and odourless radioactive gas. It comes from the radioactive decay of radium, which in turn comes from the decay of uranium. Radon is emitted from uranium-bearing soils and emission rates therefore vary depending on the geological conditions of the location. Radon is implicated in the cause of lung cancer. Protection from exposure to radon at work is specified in the Ionising Radiation Regulations[52], made under the Health and Safety at Work etc. Act[53]. A limit for radon in non-domestic buildings has been set at 400 $Bq \cdot m^{-3}$, above which action must be taken to reduce the concentration. Guidance on appropriate action can be found in BRE report BR 293[54].

Combustion appliances and products

Adequate fresh air must be supplied to meet the requirements for combustion in fuel burning appliances. Details of these requirements are laid down in BS 6798[55], BS 5410[56] and BS 5440[57]. Part J of the Building Regulations, with its associated Approved Document[58], also governs flues from gas fired combustion appliances of up to 60 kW and from solid fuel and oil burning appliances of up to 45 kW. For guidance on how to ventilate larger installations, i.e. boiler houses and plant rooms, refer to section 2.3.18.

Guideline values for concentrations of combustion products are given in CIBSE Guide A[12], section 1, Table 1.8. The most common are nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO). These may either be created within the occupied space or may re-enter buildings, e.g. from chimney smoke or from the exhausts of cars through windows overlooking car parks.

Gas and refrigerant detection methods

Gas detection methods are dealt with in section 2.3.18. Refrigerant detection methods are also considered in that section, with further guidance in the case of split systems in section 2.4.21.

Smoke control and clearance

Ventilation for the control of smoke in the event of a fire, and its subsequent clearance, is a specialist subject. Guidance is given in CIBSE Guide E: *Fire engineering*[58]. If natural ventilation is to be achieved by means of an atrium, guidance is also available in BRE Report BR 375[59].

2.3.2.2 Ventilation for internal comfort

Temperature

CIBSE Guide A[12], Table 1.1, gives recommended summer and winter dry resultant temperatures corresponding to a mean predicted vote of ±0.25 for a range of building types. However, as noted in Guide A, control within an air conditioned building is normally based on a response to internal air temperatures. In a standard office environment this corresponds to 22–24 °C and 21–23 °C where comfort cooling or air conditioning, respectively, are available. In a naturally ventilated environment, the acceptable dry resultant temperature range is less well defined and various approaches have been suggested, see Table 2.12.

Section 1.4.3 of CIBSE Guide A[12] considers factors that influence the criteria for comfort cooled or air conditioned spaces. A summary of the factors most related to the design of the ventilation or air conditioning systems is given in Table 2.13. However, CIBSE Guide A should be consulted for detailed guidance.

Table 2.12 Alternate approaches to design criteria for naturally ventilated offices

Criterion	Source
Mean temperature during occupied periods with acceptable deviation, e.g. mean summer dry resultant temperature of 23±2 °C in an office with a formal dress code, and 25±2 °C in an office with an informal dress code	BRE *Environmental design guide*[60]
Thresholds never to be exceeded, e.g. (*a*) a maximum temperature of 27 °C; (*b*) the internal temperature is never to exceed the external temperature.	CIBSE AM10[27]
A threshold that can be exceeded for a specified period, e.g. (*a*) dry resultant temperature not to exceed 25 °C for more than 5% of the occupied period; (*b*) dry resultant temperature not to exceed 25 °C for more than 5% of the occupied period or 28 °C for more than 1% of the occupied period	CIBSE Guide A[12]; BRE *Energy Efficient Office of the Future specification*[61]

Table 2.13 Factors in office environments influencing thermal comfort relating to ventilation or air conditioning system design[6]

Factor	Issues to be considered	Guide A section number
Humidity	— Little effect on feelings of warmth for sedentary, lightly clothed people at dry resultant temperatures of 23 °C and below. — If room humidity is greater than 70% the risk of condensation and microbiological growth may be increased. Dust mite levels may also increase with high humidity.	1.4.3.1
Clothing	— The insulation value of clothing (i.e. clo value) can influence the acceptable dry resultant temperature for *sedentary* occupants, e.g. in the case of a thick pullover, a reduction of 2.1 K.	1.4.3.2
Activity	— The metabolic rate (hence heat generated) is affected by activity. For people dressed in normal casual clothing (clo = 0.5–1.0), an increase of 0.1 met corresponds to a possible reduction of 0.6 K in the recommended dry resultant temperature.	1.4.3.3
Temperature changes	— A smooth change in dry resultant temperature should be aimed at to avoid discomfort.	1.4.3.4
Adaptation and climate	— The theory of adaptive thermal comfort, i.e. that the preferred internal temperature is affected by the prevailing external conditions, is still being debated.	1.4.3.5
Age	— The requirements of older people for higher temperatures are thought to be associated with their generally lower activity levels.	1.4.3.6
Gender	— The requirements of women for slightly higher temperatures are though to be related to their generally lower clo values.	1.4.3.7
Occupants' state of health, disability, and physical condition	— Little is know about this factor, although higher temperatures are usually required for bed-ridden or immobilised people due to their lower met and clo values.	1.4.3.9
Draughts	— The influence of mean relative air speed on the thermal comfort of occupants is dependent partly upon the temperature of the moving air (see predicted mean vote (PMV), Guide A[12], section 1.4.2.2), the air flow rate, and its direction. — An excessive air flow rate can give rise to complaints of draughts, especially in winter; the back of the neck is particularly susceptible. — If the room air speed exceeds 0.15 $m \cdot s^{-1}$ the dry resultant temperature should be increased from its still value. An air speed of >0.3 $m \cdot s^{-1}$ is not recommended, unless it is in a naturally ventilated building where it is specifically for cooling. — Dissatisfaction with draughts is also affected by fluctuations in air speed. These are defined by the turbulence intensity (TI) and consequently a calculated draught rating (DR), which should not exceed 15%. — The relative air speed over a body's surface increases with activity. If activity levels exceed 1 met, 0.3 $m \cdot s^{-1}$ should be added to the air speed relative to a stationary point	1.4.3.10
Vertical air temp. differences	— The gradient in either direction (floor to ceiling and vice versa) should be no more than 3 K in the occupied zone. — If air velocities are higher at floor level than across the upper part of the body, then a maximum gradient of 2 $K \cdot m^{-1}$ is recommended.	1.4.3.11
Asymmetric thermal radiation	— This is affected by the proximity to adjacent cold surfaces e.g. single glazed windows, adjacent hot surfaces e.g. overhead radiant heaters and the intrusion of short wavelength radiation e.g. solar radiation through glazing.	1.4.3.14

Humidity

The role of humidity in maintaining comfortable conditions is discussed in section 1.5 of CIBSE Guide A[12]. An acceptable range of 40–70% RH is suggested. However, to minimise the risk of mould growth or condensation and maintain comfortable conditions, a maximum design figure of 60% RH is suggested for the design of air conditioning systems. Within naturally ventilated buildings, humidity levels as low as 30% RH (or lower) may be acceptable for short periods of time, but care is needed to restrict airborne irritants such as dust or tobacco smoke. Precautions should also be taken to avoid shocks due to static electricity through the specification of equipment and materials, e.g. carpets.

Internal gains

In the absence of information from the client, the British Council for Offices recommends the following allowances for internal gains when specifying ventilation systems[62]:

— solar gains not to exceed 60–90 $W \cdot m^{-2}$ depending upon façade orientation

— occupancy based upon 1 person per 12 m^2, but diversified wherever possible to 1 person per 14 m^2 at the central plant

— lighting gains of not more than 12 $W \cdot m^{-2}$ at the central plant

— office equipment gains of not more than 15 $W \cdot m^{-2}$ when diversified and measured over an area of 1000 m^2 or more, but with an ability to upgrade to 25 $W \cdot m^{-2}$. Local workstation levels are quoted as typically 20–25 $W \cdot m^{-2}$.

2.3.2.3 Ventilation of building fabric to avoid interstitial condensation

Many structures are vulnerable to interstitial condensation, which can cause rotting of wood-based components, corrosion of metals and reduction in the performance of thermal insulation. Condensed water can also run or drip back into the building causing staining to internal finishes or damage to fittings and equipment. The traditional view has been that these problems are caused by water vapour generated in the building diffusing into the structure.

Avoidance measures have therefore concentrated on the inclusion of a vapour control layer on the warm side of the structure, appropriate placing of insulation, or ventilating the structure to intercept the water vapour before it can condense. Ventilation is specifically required in cavities above the insulation in cold pitched and flat roofs, behind the cladding of framed walls and below timber floors.

Many problems can occur from water entrapped within materials, moving within the structure under diurnal temperature cycles. Under these circumstances it is helpful to distinguish between 'ventilated' and 'vented' air spaces. A ventilated space is designed to ensure a through flow of air, driven by wind or stack pressures whereas a vented space has openings to the outside air that allow some limited, but not necessarily through, flow of air. As the air in the space expands and contracts under diurnal temperature cycles, water vapour will be 'breathed' out of the structure. This mechanism can be very effective in large span structures where it can be very difficult to ensure effect through ventilation of small cavities.

Detailed design guidance for the provision of ventilation within structures is available in CIBSE Guide A[12], BS 5250[34] and BRE Report BR 262[63].

2.3.2.4 Energy use

Energy use in offices has risen in recent years because of the growth in IT, air conditioning (sometimes specified when not required), and intensity of use. However, this trend is offset by considerable improvements in insulation, plant, lighting and controls. The Energy Efficiency Best Practice programme has produced ECG 19: *Energy use in offices*[20]. This provides benchmarks, based on data gathered in the 1990s, which take account of increasing levels of IT provision for four types of office buildings:

- naturally ventilated cellular
- naturally ventilated open-plan
- standard air conditioned
- prestige air conditioned.

Despite perceptions to the contrary, energy-efficient offices are not expensive to build, difficult to manage or inflexible in their operation. Nor do they provide low levels of comfort or productivity. Energy-efficient techniques that work well tend to be reliable, straightforward, and compatible with the needs of the building operator and occupants. Capital costs are often similar to those for normal offices, although budgets may be spent differently; for example, on measures to reduce cooling loads rather than on air conditioning.

Further opportunities for improving energy efficiency should be sought when other changes occur, e.g. refurbishment, fit-out, alteration, and plant replacement. Building Regulations[64] and the associated Approved Document L[1] require much greater attention to energy issues during refurbishment, as the scope of the regulations in England and Wales has been widened to bring such activity within the meaning of controlled work and material change. The Scottish regulations are currently being revised and it is anticipated that they will adopt a similar approach. Best results in terms of energy efficiency are obtained when there is a good brief, good design with attention to detail, sound workmanship and commissioning, and good control and management.

Energy efficient office design can reduce energy costs by a factor of two. ECG 19[20] gives details of the characteristics of best practice energy efficient design, as well as details of the benchmarks for the four office types. Careful attention to energy efficiency should be a constant theme of the design of the ventilation and air conditioning of a building.

2.3.3 Assembly halls and auditoria

2.3.3.1 General[65,66]

Assembly halls and auditoria, e.g. theatres, concert halls, conference centres, places of worship, are generally characterised by large but variable occupancy levels, relatively high floor to ceiling heights, sedentary occupation, and stringent acoustic requirements. Places of worship tend to be serviced with a low cost, simple solutions.

Specific issues that need to be addressed for assembly halls and auditoria include the following:

- flexibility of the space being served and if the seating is fixed or removable
- acoustic control measures including plant location, vibration, noise break-out, fan noise, silencers, flexible connections, duct linings, etc.
- integration of relatively large air handling plant and distribution ductwork
- occupancy patterns and part load operation
- viability of heat recovery devices and possible variable speed operation
- zoning of the plant (for large auditoria)
- treatment and integration of builders' work plenums (including control and zoning)
- air terminal device selection, integration with seats, control of draughts and noise regeneration
- stage ventilation and cooling and assessment of lighting heat gains
- temperature control at rear of auditorium due to reduced height
- background heating, and out-of-hours heating
- cooling and ventilation to control rooms etc.

2.3.3.2 Design requirements

Normal design requirements for buildings are shown in Table 2.14. Mechanical ventilation systems for assembly halls and auditoria need to be designed to meet the sound control requirements described in section 5.

2.3.3.3 Strategies

Mechanical ventilation (low level supply, high level extract)

Low level supply is often via a plenum beneath the seating. Air is extracted at high level, returned to the

Table 2.14 Design requirements: assembly halls and auditoria

Parameter	Design requirement
Fresh air ventilation rates	To suit occupancy levels
Air change rate	3–4 air changes per hour for displacement strategy
	6–10 air changes per hour for high level mechanical strategy
Temperature and humidity:	
— heating only	20 °C; 40% RH (minimum)
— with cooling	20–24 °C; 40–70% RH

central plant for heat recovery or exhausted to atmosphere. This approach is suitable for raked fixed seating halls and auditoria. Displacement-type room air distribution strategies are often used. The advantages are that only the occupied zone is conditioned, not the entire space and the potential for 'free cooling' is maximised as supply air temperatures are usually 19–20 °C. Air volumes and energy consumption and maintenance costs are usually less when compared with high level supply, although central plant sizes are normally similar.

Mechanical ventilation (high level supply and extract)

This system is usually selected where a flexible space is required, seating is removable, or where it is not feasible or prohibitive in terms of cost to provide under-seat plenums.

Natural ventilation

Supply is by attenuated inlet builders' work ducts at low level and high level. Extract is by attenuated outlets at high level, relying on stack effect to ventilate and cool the area. This approach has potentially the lowest running costs but may require a number of provisions to ensure adequate airflow rate and to limit peak temperatures in summer. Particular considerations include providing suitable air paths, inlets and exhaust positions, solar protection, mass exposure and night cooling.

Ventilation control

Options for ventilation control strategies include:

- demand-controlled ventilation and cooling depending upon (*a*) return air carbon dioxide levels[67], (*b*) occupancy levels
- space temperature and humidity
- time control
- night-time purging of the space and possible pre-cooling of structure.

2.3.4 Atria

2.3.4.1 General

The incorporation of an atrium will not automatically lead to energy savings, especially if the atrium requires artificial lighting and air conditioning (often for the health of the planting as much as the occupants)[26]. However, if well designed, an atrium can bring the advantages of:

- enhanced opportunities for natural ventilation by stack effect and allowing air to be drawn from both sides of the building towards a central extract point
- preheating of ventilation air
- additional working space.

2.3.4.2 Requirements

Environmental conditions

Environmental conditions within an atrium are dependent upon the degree of comfort required. Saxon[68] defines four categories of atrium:

- simple unenclosed canopy or enclosure without comfort control
- basic buffer space with partial control to assist plants
- tempered buffer space with partial control to assist in achieving some degree of human comfort
- full comfort atrium.

Buoyancy driven ventilation (mixed and displacement)

Many atria are sealed and mechanically ventilated and, sometimes, mechanically cooled. However, natural ventilation can provide high rates of air change and also induce cross ventilation of the surrounding office areas. Natural ventilation is driven by wind pressure and thermal buoyancy. The limiting case is likely to be buoyancy alone, i.e. when there is no breeze.

There are two kinds of buoyancy driven ventilation, defined by the position of the openings[69]:

- mixing ventilation
- displacement ventilation.

In mixing ventilation, openings are placed at the top of the atrium only; warm air leaves the atrium reducing the pressure and allowing cool air to enter via the same opening. The cool, dense air falls to the floor mixing with the warm air as it falls. This results in the air temperature at floor level being above ambient by an amount depending on the size of the opening; the larger the opening the smaller the difference between the inside and outside temperatures. Mixing ventilation leads to a relatively uniform vertical temperature distribution.

In displacement ventilation, openings are placed at the top and bottom of the atrium; warm air leaves the upper opening and cooler air enters the lower opening. Assuming a steady input, equilibrium is reached where a stationary boundary exists between the warm air at high level and the cool air at lower level. Reducing the size of the openings lowers the position of this boundary and increases the temperature of the upper zone but the temperature of the lower zone remains at, or close to, the ambient temperature.

In many situations displacement ventilation is appropriate for summer conditions. To promote ventilation the air in the atrium should be as warm as possible over the greatest proportion of the atrium height. In most atria occupation occurs at floor level, excluding galleries and staircases. Therefore it is important to keep the temperature at floor level as low as possible. However if the atrium is open to the surrounding space, or if it provides high level walkways, the high temperatures in these occupied spaces might become unacceptable. The design strategy should therefore be based on the absorption of solar radiation by surfaces above the occupied space. The position of the stationary boundary is important; ideally the hot layer will be confined to a level above adjacent occupied spaces. This suggests that atria should have sufficient height to ensure that this will occur.

Displacement ventilation can be used to reject heat when the outside temperature is below the atrium temperature. At night, heat retained in the massive elements of the atrium will generate stack effect to provide useful night cooling. However, it is possible for the temperature in the atrium to fall below the ambient temperature and thereby cause a reversal of the stack effect.

Atrium openings

For displacement ventilation driven by the stack effect, openings will be required at the top and bottom of the atrium of between 5 and 10% of the roof glazing area[70]. For atria with large areas of vertical glazing facing between south and west, the openable areas should be a similar percentage glazing area. The more shading that can be provided, the smaller the openings need to be for a given thermal performance.

Roof vents

Roof vents must be carefully positioned within the form of the roof so that positive wind pressures do not act on the outlets causing reverse flow[27]. It is normally possible to arrange the outlets such that they are always in a negative pressure zone. This may be achieved by:

— designing the roof profile so that for all wind angles the openings are in a negative pressure zone
— using multiple vents that are automatically controlled to close on the windward side and open on the leeward side.

Ventilation enhancement and fire safety

On hot, still days natural ventilation can be supplemented by extract fans in the atrium roof. Subject to fire office approval, a combination of natural and powered ventilation can also form part of the smoke control or clearance system. It is essential that fire conditions be considered at an early stage so that the possibility and benefits of a dual-purpose system can be evaluated. Guidance on fire safety and atria is available elsewhere[39,58,70,71].

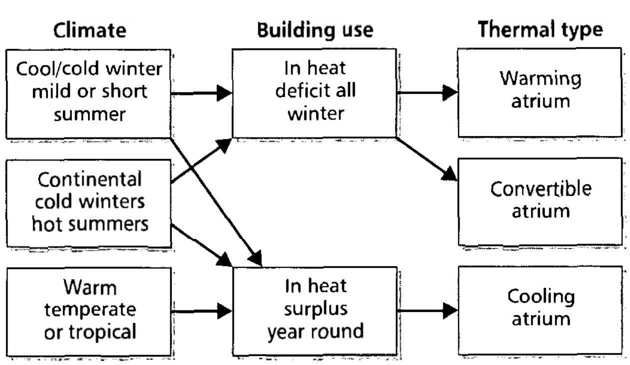

Figure 2.6 Selection of thermal type of atrium

Flexibility

The designer should be aware of any intention to use the atrium area for other purposes, e.g. concerts or the provision of catering, when selecting the ventilation strategy.

2.3.4.3 Strategies

Types of atrium

Saxon[68] defines three types of atrium with regards to their thermal properties, see Figure 2.6. These are:

— *warming atrium*: which normally collects heat
— *cooling atrium*: which normally rejects heat
— *convertible atrium*: which changes mode according to the season.

The purpose of the atrium will be affected by climate and building use as this impacts on internal heat gains within the adjacent accommodation.

(*a*) Warming atrium

(*i*) In winter

A warming buffer atrium is normally designed to admit heat freely (from solar gain or the surrounding accommodation) and will therefore tend to be at higher than ambient temperatures. Even if the atrium is unheated, its temperature in winter will be above the ambient. This may be used as a means of pre-warming ventilation air. Unless the atrium has a low protectivity[81] (i.e. the ratio of separating wall area to the atrium external envelope area), the temperature at night should be maintained above the night set-back, given the flow of heat from the building to the space and stored heat in walls and the floor. The chosen ventilation strategy will affect heating energy consumption.

Air circulation is desirable, even in winter, to avoid cold air stratifying at the ground level where people pass through. Additional heat can be gained within the atrium by coupling its ventilation system with that of the accommodation, air being discharged into the atrium after heat recovery. If full comfort is sought then coupling becomes even more advantageous. This can be achieved by using the atrium as a return air plenum. This allows solar gains to be collected and food smells to be contained.

(*ii*) In summer

The main concern in summer is to prevent overheating. The primary means of achieving this is through shading[72]. External shading is more effective than internal shading and movable devices can prevent the loss of useful daylight. The stack effect can be used to induce ventilation either of the atrium alone or of the whole building.

(*b*) Cooling atrium

The function of the atrium is to provide a source of cooling for the surrounding accommodation. This cooling can be as a result of night cooling within the atrium creating a thermal buffer zone. More commonly the atrium is used as a supply or return air plenum.

(*c*) Convertible atrium

A convertible atrium will function in a similar manner to the warming atrium in winter, but require more protection against overheating in summer to avoid the need for impractical ventilation rates. Pre-cooling of the atrium space may also be employed to reduce the temperature of any radiant surfaces.

Ventilation modes

Saxon[68] defines five possible ventilation modes:

- complete separation of ventilation for the atrium and that for the occupied space
- intake of primary air via atrium and the rest separate
- exhaust of used clean air into the atrium, the rest separate
- use of the atrium as a supply air plenum to occupied spaces
- use of the atrium as a return air plenum.

The advantages and disadvantages of these modes, with regard to degree of comfort, are shown in Figure 2.7.

	Comfort type				
	Canopy	Buffer	Temp. buffer	Full comfort	Thermal type
No vent. relationship	Normal	Normal	Possible	NA Behaves as separate room	Warming Convertible Cooling
Intake via atrium	No effect	OK summer NA OK winter	OK summer NA OK winter	NA	Warming Convertible Cooling
Exhaust to atrium	Slight effect	Useful	Useful	NA	Warming Convertible Cooling
Atrium as supply plenum	NA	NA	NA	Possible Useful	Warming Convertible Cooling
Atrium as return plenum	NA	NA	Collects solar useful	Useful	Warming Convertible Cooling

Figure 2.7 Selection of ventilation mode

2.3.4.4 Calculation of atrium performance

A suitable choice of thermal model should be made. Guidance on the prediction of winter conditions in atria at an early stage of the design is available[38]. Models for calculating ventilation flow rates such as SERI-RES, DOE-2 and BREEZE are listed in the *European Passive Solar Handbook*[72].

2.3.5 Broadcasting studios (radio and TV)

2.3.5.1 General

The general requirement is to provide a comfortable environment within the constraints imposed by the production of television programmes. Specific issues that need to be addressed include:

- high lighting loads in studios
- high occupancies for shows with audiences
- rapid changes in load
- variable operation times and periods
- sensitivity to air movement and noise
- high equipment loads in technical areas
- critical areas requiring a high degree of reliability
- 24-hour operation
- multiplicity of studio arrangements
- adaptability to respond to changing technological and business requirements.

2.3.5.2 Design requirements

Tables 2.15 and 2.16 provide some typical design requirements. The loads given apply to the working area only. The areas identified provide typical examples and not intended to be exhaustive. Arenas are often used for bigger shows. Small presentation studios may be used for linking programmes; these are subject to similar loads but of short duration and are normally occupied all day by a presenter.

Mechanical ventilation systems for broadcasting studios need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building.

Table 2.15 Typical design requirements: broadcasting studios — general areas

Description	Size / m^2	Occupancy	Noise level	Heat loads / W·m^{-2}	
				Lighting	Equipment
Flexible studio (light entertainment)	Up to 2000 (typically 400)	10 crew 50–100 audience	NR20–NR25 NR30 with audience	500, 200 over seating	100
Drama studio	150–2000	4–10	NR15	500 over 2/3rds. of floor area at any one time	100
Fixed rig studio (e.g. news and current affairs)	150	4–10	NR20–NR25	200	100
Radio studio	5–30	1–10	NR15	20	70

Table 2.16 Typical design requirements: broadcasting studios — technical areas

Description	Size / m²	Occupancy	Noise level	Equipment heat load
Control room:				
— production*	50	8–10	NR20–NR30	6–8 kW; 70 W·m^{-2}
— vision*	50	8–10	NR20–NR30	4–8 kW; 70 W·m^{-2}
— sound	16	2–3	As for studio	2–4 kW
Voice-over booth	2.5	1	NR15–NR20	2–4 kW
Editing room:				
— equipment outside room	—	1–4	NR20–NR30	2–6 kW
— equipment within room	—	1–4	NR35–NR40	1–8 kW
Central apparatus room	†	N/A	NR45	Typically 750–1000 W·m^{-2}
Transmission room	†	N/A	NR30	Up to 500 W·m^{-2}

* These areas may be combined
† Dependant on size of facility

Television studios may have 2–3 lighting rigs to suit different requirements. For programmes such as news and current affairs, which have less need to create visual interest and that run all day, fluorescent lighting may be used in addition to tungsten, thereby reducing the lighting load.

Heat loads can be highly intermittent. Game shows last for only ½ to 1 hour. During this time the lighting may be brought up and down on the audience. For drama studios, only one of a number of sets may be fully lit at a time. Setting up studios for shows can take several days, during which time loads will be low.

Within the occupied zone near floor level environmental conditions should be 21±1 °C, rising to 23±1 °C at times of peak load. Relative humidity should ideally be between 40% and 60%. Humidity control is not normally required in the UK. Achieving good humidity control in studios can be problematic due to the rapid load changes. Close control of conditions may be required in tape storage areas to reduce deterioration. It is preferable that tapes are stored under the same environmental conditions as the room in which the tapes are to be used; this minimises sticking and problems to do with static electricity.

Air speeds in television studios should be in the order of 0.2 m·s^{-1}, but not higher than 0.3 m·s^{-1} in order to avoid visual disturbance of hair, clothing, scenery drapes and dry ice, and noise in microphones. Air movement is critical for drama studios.

Mechanical ventilation systems for broadcasting studios need to be designed to meet the sound control requirements described in section 5: *Sound control*. Typical noise level criteria are given in Tables 2.15 and 2.16. Reference should also be made to the noise criteria established in the BBC's *Guide to acoustic practice*[73]. Noise is particularly critical in drama studios and 'quality' radio studios. As in other applications, background noise from a ducted air system provides a degree of masking of extraneous noise from adjacent areas. If the background noise level is substantially lower than the criterion set, then the extraneous noise normally masked by the ventilation may become apparent.

2.3.5.3 Strategies

Systems need to be able to cope with high loads and with rapid changes in load. Air-based systems are often preferred due to concerns over water within the space. Central plant may be preferred due to restrictions on maintenance access.

Variable air volume systems may provide an energy efficient solution for television studios. Constant volume systems provide an even airflow at a constant noise level, which may be important for technical reasons, but can be wasteful of energy in large installations.

Blow-through coils with airside damper control may be preferred to waterside control to respond to rapid load changes. Overcooling can be a problem if response is too slow. Steam injection may be used for fast response to meet humidity requirements.

High reliability for critical areas is normally provided by redundancy on individual units and/or in the number of units provided. Dual power supplies and generator back-up are also generally provided. High loads can lead to rapid temperature rises (that may activate sprinklers). Systems should also be designed so that they can be readily adapted to respond to changing requirements. To separate audience and performance areas for control purposes, studios may be zoned into quartiles by multiple damper assemblies.

Attenuation should be provided to reduce ingress of noise from outside and from central plant. Noise from balancing dampers can be a particular problem and should be avoided if possible. Air speeds inside the studio are critical with regard to noise, see section 2.3.5.2. Particular problems can arise with boom microphones located close to high-level supply diffusers, both due to noise from the diffuser and wind-generated noise from excessive air movement.

False floors are normally provided in studios but are not generally used for air supply since they are normally filled with cabling, including PVC cables. Acoustic and fire-break issues also need to be addressed.

Equipment heat gains in technical areas may be treated directly by providing dedicated supply and/or extract ducts to the equipment cabinets.

Radio studios are the most critical areas with regard to noise levels. Constant volume systems are preferred while the studio is in use.

Where cooling loads are relatively low, cooling systems such as displacement ventilation and chilled ceilings may be used. Where areas are occupied 24-hours a day, consideration must be given to how the systems will be maintained without loss of cooling or ventilation during studio use.

2.3.6 Catering and food processing

2.3.6.1 Kitchens

General

Adequate ventilation in catering premises is required for the following purposes:

- To introduce sufficient clean, cool air and remove excess hot air in order for the occupants to breathe and remain healthy and comfortable. Often it is not possible to achieve normal comfort conditions in kitchens because of the difficulties of counteracting the heat released from appliances. Under these circumstances care should be taken to ensure that acceptable working conditions are not breached.
- Provide sufficient air for complete combustion in appliances to prevent carbon monoxide levels exceeding 300 ppm for 10 minutes[42] or 10 ppm as an average over 8 hours[44], and to dilute and remove combustion products.
- Dilute and remove odours, vapours and steam from the cooking process.

Local ventilation must be kept clean from fat residues to avoid loss of efficiency and minimising the risk of fire.

Research by the HSE on exposure of kitchen and factory workers to cooking fumes reinforces the importance of providing and maintaining good ventilation in catering kitchens and industrial cooking areas, particularly where meat, fish and cooking oils are directly heated. A fundamental requirement of the Control of Substances Hazardous to Health (COSHH) Regulations[42] is that employers should prevent the exposure of their employees to hazardous substances or, where that is not reasonably practicable, ensure that there is adequate control of hazardous substances. The fumes generated by directly heating foods during frying, grilling and stir-frying have been identified as containing small quantities of carcinogens. Although deemed to be adequate, available information on this issue is limited at the time of writing, making it impossible to state conclusively that no risk exists with current controls. It is therefore important that fume extraction systems are provided and maintained to current standards. Designers should ensure that they are aware of latest revisions to any related guidance.

Requirements

(*a*) Canopy extract

Air needs to be removed from cooking and subsidiary areas at a constant rate to take away combustion fumes and cooking odours as close to the source as possible. It is advisable that the bulk of extraction from the kitchen is via hoods above gas-fired and all other appliances capable of generating heat, water vapour, fumes and odours.

It is recommended that the plan dimensions of the canopy exceed the plan area of cooking appliances. An overhang of 250–300 mm all round is normally adequate for island canopies. Wall-mounted canopies normally have a overhang of 250 mm at the front and 150 mm at the sides. Greater overhangs may be required at some appliances.

Canopies and ductwork need to be constructed from non-combustible materials and fabricated so as not to encourage the accumulations of dirt or grease, nor to allow condensation to drip from the canopy. The ductwork needs suitable access for cleaning and grease filters need to be readily removable for cleaning or replacement.

The amount of air extracted via the canopies should be calculated from the information supplied with the particular appliances, and not based simply on general advice or overall air change rate. Where details of the equipment are known, HVCA specification DW 171[74] describes a method for calculating the ventilation requirement whereby each cooking appliance is allocated a thermal convection coefficient. This is the recommended volume of air to be extracted in $m^3 \cdot s^{-1}$ per m^2 of surface area of the appliance. The area of each appliance is multiplied by the coefficient for that appliance and the values for each item of equipment under the canopy are added together to determine the total volume to be extracted. The factor will vary depending on whether the appliance is fired by gas or electricity.

Where the ventilation requirements of the individual cooking appliances are not available, an approximate air flow rate can be calculated from the total hood size, canopy area and hood face velocity, as follows:

$$Q_{\text{hood}} = 1000 \times A_{\text{hood}} \times V_{\text{hood}} \qquad (2.3)$$

where Q_{hood} is the approximate hood air flow rate (litre·s^{-1}), A_{hood} is the canopy area (m^2) and V_{hood} is the hood face velocity (m·s^{-1}). Table 2.17 provides typical hood face velocities.

Table 2.17 Hood face velocities

Cooking duty	Hood face velocity / m·s^{-1}
Light	0.25
Medium	0.4
Heavy	0.5

(*b*) Ventilated ceiling extract

Where ventilated ceilings are used in place of canopies, the ventilation rates should be calculated taking into account room size and function. As a guide, a ventilation rate of not less than 17.5 litre·s^{-1} per m^2 of floor area and not less than 30 air changes per hour (ACH) is advisable. A lower air change rate may be needed to avoid discomfort from draughts where the kitchen is divided into separate rooms. The Heating and Ventilating Contractors' Association recommends that a general ventilation rate of 40 ACH be used in areas of larger kitchens not treated by canopies.

(*c*) Replacement air

If the kitchen is in a sealed area (i.e. not adjacent to dining areas) replacement air should comprise typically 85% supplied by mechanical ventilation and 15% by ingress of air from the surrounding areas. This ensures that the kitchen is maintained under a negative pressure to prevent the escape of cooking odours. In basement areas containing kitchens and restaurants, the supply plant to the restaurant areas should be sufficient to offset the down-draught from street level in addition to supplying air to the kitchens.

If non-air conditioned, properly ventilated restaurants adjoin the kitchens, the majority of air may be drawn from the dining area. If the restaurant is air conditioned, air may be drawn from it at a maximum of 7 litre·s^{-1} per person. The difference between the extract and replacement air should be provided by a separate kitchen supply system.

Air drawn from adjacent areas should be clean. It is not advisable to draw make-up air from rooms where smoking is allowed. Where make-up air is drawn via serving hatches or counters it is recommended that air velocities do not exceed 0.25 m·s^{-1} to avoid complaints of draughts. However, higher velocities may be tolerated or desirable at hot serving counters. The make-up air can be drawn in through permanent grilles if the serving hatches are small or likely to be closed for long periods. These should be sized on the basis of 1.0–1.5 m·s^{-1} airflow velocity.

The incoming air from the ventilation system needs to be arranged so as not to affect adversely the performance of flues associated with open-flued gas appliances[75].

In smaller kitchens sufficient replacement air may be drawn in naturally via ventilation grilles in walls, doors or windows. Provision should be made to prevent pest entry by using a fine mesh in the grille; however, it may be necessary to compensate for restrictions in the airflow by increasing the size of the grille.

(*d*) Cooling air

The effective balancing of incoming and extracted air, together with removal at source of hot vapours, should prevent the kitchen from becoming too hot. Air inlets from mechanical ventilation systems can be positioned to provide cooling air over hot work positions. Extra provision may be required, either by an overhead outlet discharging cool air or by air conditioning. Free standing fans are not recommended due to health and safety considerations and their effect on the efficiency of the designed ventilation systems.

(*e*) Discharge

High level discharge of extracted air, with discharge velocities of about 15 m·s^{-1}, are often needed to prevent nuisance to neighbouring properties. The design of the discharge stack should prevent down-draughts and re-entry of fumes into the building.

2.3.6.2 Food processing

General

Food processing covers cooking, preservation and packing. Normally, mechanical ventilation, and sometimes air conditioning, will be required.

Requirements

The designer should take into account the heat dissipation based on the energy used in the production process and should make an approximate heat balance for the calculation of air quantities. The ventilation of special food manufacturing processes will need detailed consideration in consultation with food production specialists/managers. Plant may need to be designed to meet individual requirements; for example, a fairly closely controlled temperature is necessary in sweet and chocolate manufacture and local cooling is an essential part of the manufacturing process.

In cooking areas the general guidance given in section 2.3.6.1 applies. In addition to local ventilation, general ventilation will be necessary. It is preferable to supply air over working areas and extract over cooking equipment or other high heat dissipation areas, but care must be taken to avoid local excess cooling of the processes.

Regular maintenance of kitchen ductwork is essential to reduce the risk of fire[74]. Ductwork should be routed in a manner that will enable routine cleaning to be carried out. Drains may be necessary in some cooling processes, as may fire dampers and grease filters.

2.3.7 Cleanrooms

2.3.7.1 General

A cleanroom is a room in which the concentration of airborne particles is controlled to specified limits and which is constructed and used in a manner to minimise the introduction, generation and retention of particles within the room. Cleanrooms are classified according to the maximum permitted number of particles of a certain size. Commonly used classifications are given in BS EN ISO 14644-1[76] and FS209E[77], see Table 2.18. The appropriate classification must suit the work that is to be undertaken and it is often the nature of the work that will dictate the arrangement of the ventilation systems.

Table 2.18 Comparison of cleanroom classifications

USA Federal Standard 209E[77]	BS EN ISO 14644-1[76]	MCA[78] ('at rest')
—	1	—
—	2	—
1	3	—
10	4	—
100	5	A or B
1000	6	—
10 000	7	C
100 000	8	D

The Medicines Control Agency (MCA), which publishes the *Rules and Guidance for Pharmaceutical Manufacturers and Distributors*[78] (known as the 'orange book'), uses the FS209E classifications and, in addition, sets limits for microbiological contamination. Classifications may also relate to 'as built', 'at rest' and 'in operation' states.

The appropriate classification must be agreed with the client as the cleanroom suites will often require validation in terms or air change rates, particle counts and other environmental criteria.

Information on the design of cleanrooms is available within the series of *Baseline Guides* produced by the International Society for Pharmaceutical Engineering*.

*International Society for Pharmaceutical Engineering, 3816W Linebaugh Avenue, Suite 412, Tampa, Florida 33624, USA (http://www.ispe.org)

2.3.7.2 Design requirements and strategies

Generally, the design of the ventilation systems must take account of the following factors, which will need to be agreed with the client:

— classification, i.e. 'at rest' or 'in operation'
— nature of work, e.g. semiconductor/electronics or pharmaceutical
— laminar or turbulent flow requirements
— minimum air change rates
— pressure differentials
— room construction, fabric leakage rates and other air paths
— HEPA filtration standards
— room layout, including fittings and equipment
— open or closed door design
— controls and alarms
— validation requirements.

Mechanical ventilation systems for cleanrooms need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building.

Filters are one of the major influences on the level of cleanliness in cleanrooms, but must not be considered in isolation. The method used to supply air to the room is a crucial factor, along with how the room is used in operation. The location of fixed furniture, equipment and workstations needs to be considered as they affect airflow patterns and create dead zones within the room. Wherever possible the product should be upstream of the operative. The cleanest zone is the area in immediately in front of the HEPA filter and the product should be in this zone if possible. There should special clothing for operatives with changing rooms etc. Variable speed fans should be used to maintain constant airflow when HEPA filters become dirty. Clean benches are frequently used to upgrade a section of the clean room or carry out work in a normal working area.

Air can be supplied by laminar- or non-laminar-flow methods. Airflow patterns may need to be controlled or located so that the cleanest air can be directed across workstations where the tasks are actually performed.

Non-laminar-flow cleanrooms can achieve up to USA Federal Standard 209E class 1000, whilst laminar-flow clean rooms can achieve class 1 in 'in operation' state. Turbulent-flow clean rooms may achieve higher classifications in 'at rest' state. Non-laminar-flow systems can achieve FS209E 'at rest' class 100 (MCA grade B). Such systems are common in pharmaceutical applications.

In non-laminar-flow clean rooms, air is supplied to the room by individually ducted HEPA filter modules or air diffusers in the ceiling. Alternatively, an in line HEPA filter housing installed in the supply duct as close to the room as possible can be used. The grade of HEPA filter specified will need to suit the room classification. Air should be exhausted through grilles in the walls near the floor as there is no requirement on uniformity of airflow patterns. Air velocities must ideally be between 0.15 and 0.45 $m \cdot s^{-1}$; lower velocities allow contamination to settle out, high velocities allow contamination to agglomerate.

For non-laminar-flow cleanrooms, observation of certain design criteria is essential. Table 2.19 provides general design guidance for non-laminar-flow clean rooms.

In laminar-flow cleanrooms, air enters the room through filters covering the whole ceiling (downflow) or on one wall (crossflow), and is exhausted through the entire opposite surface, with air flowing in parallel lines and at uniform velocity. Thus, air makes only one pass through the room and any contamination created in the room is carried out. Velocities of 0.45 $m \cdot s^{-1}$ are necessary to prevent settling out. Such rooms are costly to construct and it may be appropriate to subdivide the room into areas having different classifications according to the processes being undertaken. Due to the quantities of air being circulated some form of recirculation should be considered to reduce energy costs. Table 2.20 provides general design guidance for laminar-flow clean rooms.

Table 2.19 Design guidance for non-laminar-flow clean rooms

Parameter	Value for achievable class (USA Federal Standard 209E)[77]		
	1000	10 000	100 000
Room pressure differential to adjacent areas	15 Pa	15 Pa	5–10 Pa
Ventilation rate (depending on type ofwork)	40–120 ACH	20–40 ACH	10–20 ACH
Clean air inlet area as a percentage of ceiling area (typically for 'in operation'status)	20–50	10–20	5–10
Terminal velocity at clean air inlet	0.15–0.45 $m \cdot s^{-1}$	0.15–0.45 $m \cdot s^{-1}$	0.15–0.45 $m \cdot s^{-1}$
Return locations	Low level or floor	Low side wall	Side wall or ceiling
Wall return spacing	Continuous on all four walls	Intermittent on long walls	Non-uniform
Return face velocities	0.5–1 $m \cdot s^{-1}$	1–2.5 $m \cdot s^{-1}$	2.5 $m \cdot s^{-1}$

Note: Air supply may be drawn from outside or recirculated, subject to client requirements

Table 2.20 Design guidance for laminar-flow clean rooms

Parameter	Value for achievable class (USA Federal Standard 209E)[83]	
	1 and 10	100
Room pressure	15 Pa	15 Pa
Ventilation rate	500–600 ACH	500 ACH
Clean air inlet area as a percentage of ceiling area	90–100%	90%
Terminal velocity at clean air inlet	0.15–0.45 $m \cdot s^{-1}$	0.15–0.45 $m \cdot s^{-1}$
Return locations	Perforated wall/floor	Low level or floor

2.3.8 Communal residential buildings

2.3.8.1 General[79]

Communal residential properties are buildings containing separate residential units with some degree of communal facilities. For the purposes of this Guide, the following have been considered:

- residential care homes
- student accommodation
- military barracks.

As with domestic properties, effective ventilation is best provided by reducing air leakage, extracting moisture and pollutants at source, and providing occupant controllable ventilation. Natural ventilation is particularly suitable for achieving this.

2.3.8.2 Requirements

Overall ventilation rates of between 0.5 and 1 air change per hour are generally appropriate.

Wherever possible, residents should be able to maintain autonomy and control over their immediate environment. In the case of student accommodation the emphasis is on dealing with intermittent occupation and appropriate integration with heating system controls. In residential care homes occupancy is less intermittent and control of the heating and ventilation is likely to be more centralised under the control of a warden.

For communally shared facilities within residential care homes and student accommodation, it will be necessary to make different arrangements for areas of higher occupancy (e.g. television rooms) or areas of excessive moisture or odour generation (e.g. laundry rooms, and cafeteria areas) requiring ventilation direct to the outside.

Within residential care homes it may be necessary to service conservatories, which should, if possible, be separated from other living spaces by doors to prevent excessive heat loss in winter. External draught lobbies or revolving doors should be specified for all major entrances/exits.

In both types of accommodation the needs of smokers may affect the chosen system design, in particular the servicing of smoking lounges. However, as stated above on page 2-15, it should be noted that the provision of ventilation cannot completely remove the health risks associated with cigarette smoke.

2.3.8.3 Strategies

The required ventilation rates can be achieved by using trickle vents with passive stack ventilation (PSV)[80] systems or extract fans in kitchens and bathrooms. Alternatively, whole-building ventilation systems with heat recovery (MVHR) can be used if the building is well sealed. CIBSE TM23: *Testing buildings for air leakage*[11] recommends an air leakage index of 8 $Pa{\cdot}m^3{\cdot}h^{-1}$ at 50 Pa as good practice for dwellings with balanced whole-house mechanical ventilation and 15 $Pa{\cdot}m^3{\cdot}h^{-1}$ at 50 Pa for dwellings with mechanical ventilation. Best practice standards for such dwellings are 4 and 8 $Pa{\cdot}m^3{\cdot}h^{-1}$ at 50 Pa, respectively.

2.3.8.4 Further considerations

The maintenance implications of MVHR systems must be considered[81], as must the consequences of system failure if there is no passive ventilation back-up. Guidance on system optimisation is available, see section 2.4.4 and elsewhere[82].

2.3.9 Computer rooms

2.3.9.1 General

Under operational conditions, computer equipment is susceptible to the temperature, humidity and the cleanliness or otherwise of the surrounding environment. Computer rooms have a number of specific characteristics that need to be taken into account when selecting and designing ventilation and air conditioning systems. These include:

- 24-hour operation
- high sensible loads (typically 500 to 1000 $W{\cdot}m^{-2}$)
- low occupancy and latent loads
- close control of temperatures and humidity required
- high levels of reliability required, with some redundancy to ensure 24-hour operation
- deep raised floors to deal with extensive cabling
- noise levels generally above those for offices due to the computer equipment
- capability for expansion to allow for frequent upgrading of computer equipment
- mainframe computers with tight temperature control requirements may require dedicated chilled water systems.

Mechanical ventilation systems for computer rooms need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building.

It is particularly important to establish the required loading of the space, the specific requirements of any mainframe computer and the capability for expansion as these are subject to wide variations.

To minimise the effect of the external environment, computer suites are generally provided with highly insulated walls, floors and roofs, and no windows. The building structure should be airtight and vapour-sealed to facilitate close control. Air locks may also be provided at entrances. In many instances computer rooms will normally operate with the lighting off for much of the day.

Heating should be provided in critical areas to maintain a suitable minimum temperature under winter conditions during computer shutdown.

Computer rooms can be grouped into three approximate size categories:

- *small*: in offices, typically 1% of area served, often less critical than larger computer rooms; telephone equipment rooms
- *medium*: IT-intensive organisations, such as financial organisations with dealing facilities, typically 1–2% of area served on the floors plus 2–5% for a main computer room
- *large*: stand-alone data centres; switching centres.

2.3.9.2 Design requirements

Typical design requirements for computer rooms are shown in Table 2.21.

Requirements should be checked with equipment manufacturers as wider control bands and higher temperatures may be permissible.

2.3.9.3 Strategies

To provide close control of temperature and humidity, specialist computer room air conditioning units are normally provided. These units generally include:

- cooling coil (DX, glycol or chilled water)
- reheat coil (usually electric due to limited use)
- humidifier (typically steam due to straightforward maintenance and health and safety requirements)
- filtration (panel filters)
- fans (single or multiple dependent on duty)
- compressors (DX and glycol units only).

The units can be mounted within the computer room or in service corridors adjacent and come in a variety of sizes. Various degrees of sophistication are possible depending on the reliability required from the individual units. The most usual arrangement is a wardrobe-type unit with common fan drives, controls, heater battery, cooling coil and humidifiers. Reliability is then improved by incorporating redundant units. Alternatively 'modular' units can be used with common controls but individual fans, heaters, cooling coils and even humidifiers in each module, so that a module failure has little effect on the overall performance.

Table 2.21 Typical design requirements: computer rooms

Parameter	Requirements
Internal temperature	To suit computer equipment: typically 21 ± 2 °C; rate of change not to exceed 3 $K \cdot h^{-1}$
Internal relative humidity	50 ± 5% RH; rate of change not to exceed 10% in 1 hour
Filtration	To suit computer equipment: typically 60% efficiency to BS EN 779[83]
Noise criteria	NR55 (range NR45–NR65)
External temperatures	Design temperatures based on a 1% failure rate may not be acceptable; heat rejection plant in particular requires careful selection to ensure it can perform in practically all conditions
Internal heat gains	600 $W \cdot m^{-2}$ sensible (range 500–1000 $W \cdot m^{-2}$)
Ventilation	Computer rooms are generally pressurised by oversupply (1 ACH typical) to prevent infiltration gains and local variations in temperature and humidity; otherwise minimum fresh air to suit occupancy.

To a large extent, the choice of the type of cooling will be determined by the size of the computer room and the availability, or otherwise, of chilled water. DX cooling is generally used in smaller rooms where chilled water is not readily available 24 hours a day. The DX cooling coil rejects heat through external air cooled condensers. On large installations the proliferation of air-cooled condensers tends to present an unacceptable solution.

Glycol systems are based on a DX cooling coil in the room unit with heat rejection into a glycol closed water system. Dry air coolers are used to reject heat from the glycol system either centrally or on an individual unit-by-unit basis. An additional 'free cooling' coil can be added to the room unit to allow it to operate without running the compressors when the external ambient temperature is low. Glycol systems are generally used for large computer rooms where 'free cooling' can save significant amounts of energy.

Chilled water room unit cooling coils fed from a central chilled water system may be used in smaller rooms where chilled water is available 24 hours a day, and in larger rooms where simplicity of the room unit may have a benefit.

A high sensible cooling ratio is an important consideration for any selected unit to minimise the operation of the cooling coil and humidifier together. Elevated chilled water temperatures (e.g. 10–16 °C) may be used for this reason. The higher temperatures also provide the energy benefit of increased central refrigeration plant efficiency.

Common controllers can be provided but it is usual for each unit to be separately controlled to cater for variations in gains across the computer room. Common central monitoring of the alarms is usual.

To improve system redundancy, dual pipework systems may be used. Generator back-up for the cooling system is normally provided in critical applications. This may be a 'no-break' facility where high loads would give an unacceptable temperature rise between power failure and the generators coming on-line.

Air supply is normally through the ceiling or floor. Supplying air at low level and extracting over the computer equipment has the advantage that the heat released upwards from the equipment can more easily be removed without it affecting the occupied areas. High level supply may be through diffusers or a ventilated ceiling.

Consideration should be given to the operating and maintenance requirements of the installation. Temperature and humidity recording/alarm devices may be necessary together with other operational alarms. Locating equipment in an adjacent service corridor may be preferred for critical/sensitive applications as this will reduce maintenance access requirements to the space.

2.3.10 Dwellings (including high rise)

2.3.10.1 General

Fresh air supplies within dwellings are necessary for:

— the health and safety of the occupants

— the control of condensation, often the dominant pollutant arising from moisture generated by cooking, washing and clothes drying

— the removal of odours

— the removal of pollutants such as VOCs

— the removal of allergens arising from dust mites

— the safe operation of combustion appliances.

As moisture is the most significant pollutant, its control forms the basis of the ventilation strategy. The key is to avoid a situation where the relative humidity exceeds 70% for a prolonged period[84]. This can usually be achieved with a whole house ventilation rate of 0.5 air changes per hour[85]. Alternatively, more rapid extraction in response to moisture release within the dwelling, either by humidity sensors or manually, can be beneficial in removing moisture before it is absorbed by furnishings and/or the fabric of the building itself[86].

In domestic situations, it is particularly important to inform occupants of the intended operation and purpose of the selected ventilation system to ensure that it achieves its intended purpose. This will ensure that they:

— do not tamper with the system in the belief that it is costing them money to run

— do not interfere with the performance of the system through blocking air inlets or extracts, or by altering sensor settings.

2.3.10.2 Requirements

As with non-domestic buildings, the underlying concept should be to 'build tight, ventilate right'[85]. Detailed guidance on requirements and acceptable ventilation solutions can be found in Approved Document F[37]. Guidance on achieving an airtight construction can be found in CIBSE and BRE publications[11,87].

Figure 2.8[88] illustrates the impact of uncontrolled air leakage on the ventilation rate. The greater the air leakage the greater the ventilation rate and the more varied and uncontrollable it will be. Air leakage must often be reduced to bring the overall ventilation rate within the prescribed range. The airtightness of UK dwellings can range from 2 ACH to above 30 ACH at an applied pressure of 50 Pa. This equates to an air infiltration rate of 0.1–1.5 ACH, with an average of 0.7 ACH. Target air leakage rates for domestic properties are:

— 5–7 ACH at 50 Pa for dwellings having local extraction and background ventilation

— 4 ACH at 50 Pa for dwellings having whole house ventilation systems.

2.3.10.3 Strategies

The normal strategy is to extract directly at source from wet zones using mechanical extract ventilation (local or whole-house) or passive stacks. Fresh supply air is brought into the living rooms and bedrooms either by natural ventilation methods or as make-up, either induced by the negative pressure or via a mechanical whole-house ventilation system. Additional ventilation may be necessary if smoking takes place. However it should be noted the health risks of smoking cannot be completely eliminated by ventilation (see page 2-15).

In high radon areas, sealing the foundations, combined with sub-floor venting, may be required. Specialist advice should be sought. Guidance is available from BRE[89].

Balanced flue combustion appliances are preferable in dwellings fitted with mechanical ventilation incorporating extraction, as their operation is not affected by pressure differences. Guidance on safety relating to combustion products is provided in BS 5440[57] and BS 5864[90] and Building Regulations Approved Document J[38].

Passive stack ventilation[91]

A passive stack system comprises vents located in the kitchen and bathroom connected via individual near-vertical circular or rectangular ducts to ridge or tile terminals. Moist air is drawn up through the ducts by a combination of stack and wind effects. The ducts, which are normally 80–125 mm in diameter[92], should have no more than two bends at greater than 30° to the vertical to minimise the resistance to air flow, and be insulated where they pass through cold spaces to reduce the risk of condensation. Replacement air enters via trickle or similar ventilators located in the 'dry' rooms and via air leakage.

Standard passive stack ventilation (PSV) systems have a simple inlet grille to the duct. Humidity sensitive vents are available that can provide increased flows when humidity is high. Acoustic treatment may be required to reduce ingress of external noise. Fire dampers are required where ducts pass through a fire-separating floor.

PSV systems can be combined with extract fans in hybrid systems, the fan being located in the kitchen.

Advantages:

— No direct running costs.

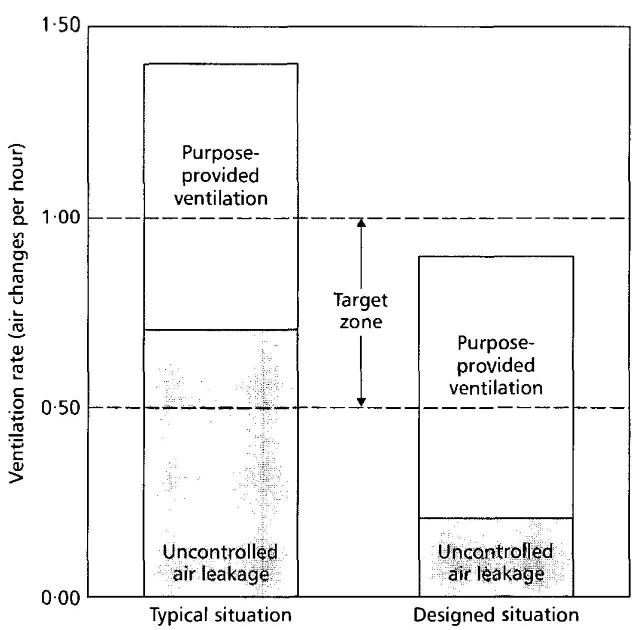

Figure 2.8 Impact of air leakage on ventilation rate

— System will last the lifetime of the building.

— System is silent in operation.

— System requires no electrical connection.

Disadvantages:

— Ventilation rate can be highly variable.

— Ventilation rate may be inadequate in poorly ventilated dwellings.

— Existing house layouts may make it difficult to accommodate duct runs.

— Site installation must be of good quality to avoid flow restrictions and excessive pressure drops.

— Uncontrolled systems waste energy due to continuous operation.

Local extract fans[86]

These are installed in kitchens and bathrooms to provide rapid extraction (typically 15–60 litre·s^{-1}) of moisture and other pollutants. They normally operate under occupant control or humidity control, or operate in association with door or light switches. Fans can be window, ceiling or wall mounted but are most effectively located at high level away from the source of fresh air, i.e. an internal door or trickle ventilator. In a kitchen they are ideally combined with a cooker hood. Ceiling mounted fans should be ducted to outside; however, it should be noted that ductwork lengths of as little as 1 m can considerably impair performance if an incorrect type of fan has been fitted[93]. Replacement air is provided by trickle ventilators or air leakage.

Fans should be located so as not to produce draughts and so as not to draw combustion products from open-flue appliances[38,90,91]. Note that cooker hoods require permanently open vents as close as possible to the hood. Control can be by manual switching or through being wired into door or light switches. Another option is humidity control with manual override, although the sensor may cause the fan to operate when moisture generation is not taking place, e.g. on warm humid summer days. The sensor needs to be positioned with consideration to where the major source of moisture is located. It may be more suitable to install cowled shutters to avoid noise problems with external gravity back-draught shutters rattling in the wind.

Advantages:

— Simple and widely applicable.

— Provides the possibility of rapid extract.

— System is easily understood.

Disadvantages:

— Perceived by occupants to have high running costs and is prone to tampering by occupants.

— Noise can be an issue.

— System requires occasional maintenance.

Heat recovery room ventilators[88]

These are a development of the extract fan and are mounted in external walls. They incorporate a heat exchanger that recovers approximately 60% of the heat from the outgoing air. This is passed across to the incoming air to preheat it. The extract fan is often dual speed, providing low speed continuous trickle ventilation or high speed extract. High-speed extract can be under manual or humidity control.

Advantages:

— Provides continuous low level ventilation.

— Provides the option of rapid extract.

— Recovers heat energy.

— Allows filtration of the supply air.

— Almost silent in operation at trickle speed.

Disadvantages:

— Occupants perceive the systems to have high running costs.

— Regular maintenance is required.

— Some recirculation is possible, due to the close proximity of supply and extract grilles.

Mechanical supply ventilation[94]

A fan unit is typically mounted in the roof space and delivers air that has been filtered and tempered by the roofspace into the dwelling. The system works on the principle of continuous dilution, displacement and replacement of air in the dwelling. Air discharge from the dwelling is via purpose provided egress vents and/or leakage paths. Fans typically run continuously at low speed, with manual or humidity controlled boost to a higher speed when required. Temperature controls can incorporate single roof space sensors or sensors in both the roof and living spaces. The latter system adjusts the flow rate of the unit to suit the temperatures in both spaces, thereby providing the optimum energy benefits for the occupants. Fan units incorporating highly efficient motor technology can provide a significant net energy gain to the dwelling.

Advantages:

— Simple and well established as a means of controlling condensation.

— Compatible with open flued appliances.

— Utilises any heat gain in the loft space.

— Allows filtration of the air before it enters the space.

Disadvantages:

— Occupants perceive the systems to have high running costs.

— Noise can be an issue.

— Systems are prone to tampering by occupants.

— Regular maintenance is required.

— Limited research has been carried out into system performance.

— Effectiveness depends on building shape/ layout.

Continuous mechanical extract[94]

Continuous mechanical extract ventilation is a simpler alternative to a supply and extract system (see below). Further information on design, installation and operation is given in BRE Digest 398[81].

Whole-house mechanical ventilation[81]

A whole-house mechanical ventilation system normally combines supply and extract ventilation in one system. A heat exchanger can be incorporated to preheat the incoming air. These systems can be effective at meeting part of the heating load in energy efficient dwellings thereby helping to distribute the heat. Typically, warm moist air is extracted from kitchens, bathrooms, utility rooms and WCs via a system of ducting, and passed across a heat exchanger before being exhausted. Fresh incoming air is preheated and ducted to the living room and other habitable rooms.

Ducts may be circular or rectangular and range in size from 100 to 150 mm in diameter. Air velocities should be kept below 4 $m \cdot s^{-1}$. Vertical exhaust ducts should be fitted with condensate traps, horizontal exhaust ducts should slope away from fans to prevent condensate running back. Both supply and extract grilles should be located at high level as far as practical from internal doors, but at a sufficient distance from each other to avoid 'short circuiting', i.e. a minimum of 2 m. Suitable louvres or cowls should be fitted to prevent ingress of rain, birds or insects.

Such systems can provide the ideal ventilation almost independent of weather conditions. During normal operation the total extract airflow rate will be 0.5–0.7 ACH based on the whole dwelling volume, less an allowance for background natural infiltration if desired. Individual room air change rates will be significantly higher, possibly 2–5 ACH, in rooms with an extract terminal. To be most effective a good standard of air tightness is required, typically better than 4 ACH at 50 Pa. Airflows need to be balanced at the time of installation. Extract rates from bathrooms and kitchens can be boosted during times of high moisture production although care should be taken not to cause draughts. The system can be acoustically treated to reduce noise ingress.

Transfer grilles are necessary only if the system is part of a warm air heating system but may be fitted in other cases, if desired. If the bottom edges of internal doors clear the floor surface by 5–8 mm there is likely to be sufficient opening for air movement. Transfer grilles are usually positioned not more than 450 mm above the floor. If placed higher they may allow the rapid movement of toxic combustion products or facilitate the spread of fire. Fire dampers should be inserted where the ductwork passes through separating walls and floors, and are desirable in kitchens, e.g. cooker hoods.

It is claimed that such systems are effective in reducing condensation due to the controlled ventilation and air-tight structure reducing cold air draughts. Manufacturers also claim that they improve indoor air quality and help in controlling dust mite populations.

Advantages:

- Provides controlled preheated fresh air throughout the house.
- Reduces the heating demand in very airtight dwellings.
- Reduces the risk of condensation.

Disadvantages:

- Ductwork can be difficult to accommodate.
- Initial costs are high.
- The systems has an ongoing maintenance liability: 6-monthly or annually.
- An adequate level of airtightness must be provided.
- Installation and commissioning is more complex than for other systems.

Comfort cooling and air conditioning

Systems are available which incorporate a heat pump into a whole-house mechanical ventilation system. Little information is available on their performance[95]; similarly with other proposed systems of domestic comfort cooling or air conditioning[96]. The decision to install such systems in domestic properties should not be taken lightly and designers should concentrate on enhancing the fabric performance to eliminate this need. If a comfort cooling and air conditioning system is proposed, key concerns for the occupants would be the ongoing maintenance requirements and acoustic considerations, both internal and external.

2.3.10.4 High rise dwellings

See section 2.3.12 for non-domestic high rise buildings.

High rise dwellings pose particular problems because of wind-induced pressures at the higher levels, i.e. above 6 storeys. This requires that special attention be paid to trickle ventilator selection[96–100]. Whole-house mechanical ventilation systems, see above, are an option[101].

If every dwelling unit comprises a self-contained ventilation system, care must be taken to ensure that inlets to dwellings e.g. windows, trickle ventilators, or mechanical air intakes are not contaminated by ventilation outlets or combustion flue gases from adjacent dwellings. This may encourage the use of centrally ducted ventilation and heating systems[93], particularly in gas or oil heated properties.

The balancing of common toilet and bathroom ducts in high rise buildings is considered in section 2.3.12.

2.3.11 Factories and warehouses

This section considers the ventilation of industrial buildings and warehouses; see section 2.3.15 for ventilation of industrial processes.

2.3.11.1 General

Minimum ventilation rates are determined by the fresh air requirements for occupants laid down in the Factories Act[102] and Health and Safety at Work etc. Act[103]. However these requirements are often exceeded by other criteria such as the ventilation requirements of the particular manufacturing processes.

There is no simple relationship between the building and process energy. The combination can be considered as:

- *Process incidental*: i.e. the process makes few demands on the internal environment. In many ways requirements are similar to office accommodation except that the space may be taller, the systems less sophisticated and environmental conditions often less demanding.
- *Process significant*: i.e. the servicing is dictated primarily by the comfort and performance requirements of the people in the building but affected by the needs of the process, e.g. humidification for textile weaving.
- *Process dominant*: i.e. the process demands very little of the building (e.g. it may be outside) or it may totally dominate the situation, for either quality or health and safety reasons.

Suitable systems will vary depending upon the degree of separation between accommodation types. Within a well-defined office area natural ventilation may suffice. Mechanical ventilation is required where occupancy is dense or where the opening of windows is not desirable. Within the production space, refer to section 2.3.15.

2.3.11.2 Requirements

Energy use

It is often difficult to distinguish between the energy consequences of the systems required for the industrial processes and those required for the buildings that contain them. However surveys of energy use commissioned under the Energy Efficiency Best Practice Programme (EEBPP) have shown that the worst and best performing buildings can differ by more than 100% within a particular industrial sector. EEBPP Energy Consumption Guide ECG 18[104] categorises industrial buildings as follows:

- *Storage and distribution buildings*: i.e. warehouses; these are typically 7.5 m high, contain pallet racking, and are naturally ventilated to 16 °C for single shift operation during the day, condensation protection being required at night. Refrigerated warehousing requires specialist treatment.
- *Light manufacturing buildings:* these are typically 5 m high and include areas for offices, storage and dispatch. They are largely naturally ventilated with occasional local mechanical extraction. Shift operation may be longer than for storage buildings.
- *Factory/office buildings*: these are typically 4 m high, possibly with a suspended ceiling in office areas, with little other differentiation between production, office and storage spaces. Some local mechanical ventilation or air conditioning may be present.
- *General manufacturing buildings*: these are typically 8 m high to accommodate tall equipment, gantry cranes and local storage racking. Mechanical ventilation may be provided to areas of high heat gain or for the clearance of process contaminants.

Table 2.22 provides energy targets relating to ventilation. However, these figures should be treated with caution, as the industrial building stock is extremely diverse; for example, high bay warehouses of 14 m height are not included in this classification. Further guidance is available on establishing building specific energy targets[105].

Table 2.22 Building related energy use[104]

Classification	Electricity consumption for fans, pumps and controls / $kW \cdot h \cdot m^{-2}$ per year	Total electricity consumption of building / $kW \cdot h \cdot m^{-2}$ per year
Storage and distribution	5	50
Light manufacturing	6	55
Factory-office	10	31
General manufacturing	10	20

Air infiltration control

Air infiltration typically accounts for as much as 30% of the heat loss of an industrial building[105]. To minimise air infiltration problems the following needs consideration:

- structural integrity should be checked by infra-red thermography
- external windbreaks should be considered on exposed sites
- if a false ceiling has been installed to reduce ceiling heights in office areas, ensure that gaps have been sealed to prevent the leakage of warm air into the ceiling void
- goods doors should not be installed facing the prevailing wind or opposite each other; if this is not possible the goods loading area should:
  - (*a*) be partitioned-off, either internally or externally, with the partitioning insulated to the same level as the external wall
  - (*b*) have rapid closing doors suitable for frequent use, either push-button or automatic, or
  - (*c*) have plastic strip curtains (although these are not a substitute for doors and there are safety considerations), or
  - (*d*) have an air curtain, or
  - (*e*) have a pneumatic seal around loading bays.

Heat recovery

See section 2.5.6 for details of heat recovery devices. Before considering heat recovery ensure that ventilation rates are minimised and can be adequately controlled. Where the extracted air is contaminated only with particles it may be possible to filter it and return it to the workplace. This eliminates heat losses but will result in more stringent maintenance requirements. If the recycled air is hot it may be discharged back into the workplace at low level during the winter; ductwork should also be provided to allow the hot air to be rejected to outside during the summer. The use of central plant will assist in the installation and economics of heat recovery but may prejudice its controllability.

Control

Plant can be controlled by time control or air flow rate control. Larger centralised systems should be zoned. Time control can be by means of:

- manual switching (should be easily accessible, with a well-labelled on/off switch)
- timeswitch
- push button or automatic presence detection allowing pre-set timed operation (useful for intermittently occupied areas)
- electrical interlock to associated production machinery (if local).

Airflow rate control can be achieved by:

- air temperature
- contaminant concentration
- number of machines in operation
- duct pressure (where zone isolation dampers are used on a centralised system).

Two-speed or variable speed motors should be considered. When contemplating reducing airflow rates, designers should be aware that limits may be in place to maintain a minimum duct velocity.

2.3.11.3 Strategies[105]

Natural ventilation

Subject to constraints imposed by industrial processes, natural ventilation can be particularly effective in industrial buildings due to the relatively high ceilings. The most effective ventilation will be obtained by using a combination of low and high level openings (e.g. windows and rooflights). With heat gains up to 20 $W{\cdot}m^{-2}$, simple systems can be used that may be cheaper to install than those relying on mechanical plant. With heat gains of 20–40 $W{\cdot}m^{-2}$, more sophisticated natural ventilation strategies may be required which may cost more to install. However, life cycle costing could demonstrate the potential for overall savings due to reduced operational costs.

It may be possible to extend the applicability of natural ventilation by grouping process equipment into a few mechanically ventilated areas. For optimum energy efficiency, any natural ventilation should be controllable as natural air change rates in industrial buildings can be quite high (particularly if goods doors are left open). The correct strategy is to design the building to be as airtight as possible and to provide the required amount of ventilation by controllable means. If space is to be subsequently partitioned off for the creation of office accommodation ensure that this will not affect the operation of the ventilation system.

Mechanical ventilation

For general factory ventilation consider the use of high level extract fans (either wall or roof mounted). These are effective at removing heat but are ineffective at controlling fumes, see sections 2.3.2.1 and 2.3.15. Consider providing all mechanical ventilation systems with back-draught shutters or dampers to prevent air infiltration when the fans are not in use.

Prevent excessive fan power requirements by ensuring that all ductwork is appropriately sized, i.e. pressure drops not more than 1 $Pa{\cdot}m^{-1}$. This usually equates to an air velocity of about 10 $m{\cdot}s^{-1}$ in main ducts and 4 $m{\cdot}s^{-1}$ in branch ducts. Over-sized fans should not be used as they will operate at sub-optimal efficiency and/or may require throttling in order to provide the suction or airflow rates required. Make-up air should be introduced to minimise energy use and discomfort, and to ensure the continued safety of heating appliances.

Make-up air

Make-up systems should be specified to provide the optimum building pressure balance. The choice of pressure balance will depend upon the processes taking place within the building, see sections 2.4.3 and 2.3.15. Negative pressures may upset heating appliances with traditional flues. Positive pressure may facilitate uniform heating and help prevent the ingress of untreated external air. Direct gas firing is a particularly efficient way of tempering large volumes of fresh air if required as make-up.

2.3.11.4 Further considerations

Automatic doors

These are probably the most energy efficient solution for low traffic situations where it is inconvenient or impracticable to open doors manually. However, they become effectively permanently open doorways when traffic is dense.

Air curtains[106,107]

Air curtains condition the incoming air at the entrance in order to minimise cold draughts. They do not act as a physical barrier to prevent the entry of outside air but use heating energy to temper air that enters the doorway. They prevent the natural convection of warm air out of the top of a doorway being replaced by cold air at the bottom.

The heat input of an air curtain must be sufficient to temper the quantity of air coming in at the entrance. An air curtain will not be effective if the velocity of the incoming air is excessive. This can occur as a result of under-pressure within the building from extract systems, stack effect with leaky or tall buildings, or wind effects on an exposed site. The width of an air curtain discharge grille should be just wider than the doorway opening; an air curtain narrower than the doorway is ineffective. Opening and closing of doors can disrupt the air stream, which takes some time to re-establish. The heating capacity of an air curtain can have an effect on the space temperature within the building entrance and suitable controls need to be fitted to adjust the heat output and air stream characteristics if necessary.

2.3.12 High rise buildings (non-domestic)

This section relates to non-domestic high rise buildings. Domestic high rise buildings are covered in section 2.3.10.

2.3.12.1 General

Whilst the aims of the ventilation strategy for buildings of 20 storeys or more do not necessarily differ from those of other buildings, there are specific design issues that need to be taken into consideration when selecting and designing ventilating and air conditioning systems. In particular these include stack effects, high winds and hydraulic pressures.

2.3.12.2 Stack effect, high winds, hydraulic pressures

Stack effects created by buoyancy pressures are magnified by the height of the building. In cold climates the interior air will usually be warmer than the outside air. Buoyancy forces cause warm air to leak out of the upper part of the building and cold ambient air to leak in at the base of the building. This will have a number of effects including:

- requiring energy to heat infiltrated air
- driving moisture into the envelope assembly, allowing condensation to form and deteriorate the materials and insulation
- creating uncomfortable draughts and possibly annoying whistling noises
- pressure differences between floor space and shafts affecting opening and closing of doors.

In warm climates a negative stack effect occurs with cold air flowing out of the base of the building and infiltration of warm moist air at the top. Moisture condensing in the cool interior environment can cause serious damage to the building materials. Envelope tightness is not usually as carefully controlled in warm climates because leakage is not as apparent; however, the potential damage is greater than that occurring in cold climate.

Features that help combat infiltration due to the stack effect(108,109) and wind pressures include the following:

- revolving doors or vestibules at exterior entrances
- pressurised lobbies
- tight gaskets on stairwell doors leading to the roof
- automatic dampers on elevator shaft vents
- airtight separations in vertical shafts
- tight construction of the exterior skin
- tight closure and seals on all dampers opening to the exterior.

The large stack effect and high winds normally mean that natural ventilation is impracticable and therefore high rise buildings are invariably mechanically ventilated or air conditioned. One possible means of reducing the stack effect is to divide the building into small self-contained units.

Airflows in extract ducts connected to vertical duct shafts in buildings can be unbalanced by stack forces, causing increased flow in some ducts and reduced, or possibly reversed, flow in others(109). Flow reversal is particularly undesirable on toilet extracts and waste disposal chutes.

A further consideration for high rise buildings is hydraulic system head pressures. Cost, safety and technical limitations relating to maximum head pressure dictate that hydraulic systems are normally split into vertical blocks of 20–25 storeys. There are a number of alternative design solutions for achieving pressure isolation including pressure separating heat exchangers, cascading water upwards to storage tanks, and installing separate systems for vertical zones within the height of the building (this last solution is complex and costly). For condenser water-type systems an intermediate sump pump could be considered. This should be located as high as possible subject to economic pressure rating. Column pressure is lost above the sump, but retained below providing partial recovery of pump energy.

2.3.12.3 System considerations

Centralised, floor-by-floor and unitary systems are all potentially suitable for high rise buildings. For centralised systems, the number of floors that can be served is limited to 10 floors above or below (20 floors for an intermediate plant room serving floors both above and below). This is the maximum number of duct take-offs that can readily be balanced. (Note that the static regain method should be considered for ductwork sizing to assist with balancing).

There are a number of issues that will impact on the choice between a centralised, floor-by-floor, or unitary approach including the following:

- tenancy requirements
- floor plate size
- riser and/or plant room space requirements
- maintenance considerations: centralised systems will be subject to large scale disruption due to localised problems or retrofit; unitary systems can require hundreds of units with the attendant management and maintenance difficulties.

2.3.13 Hospitals and health care buildings

2.3.13.1 General

The heating and cooling load associated with ventilation plant form the major component of boiler and chiller plant capacity. It is therefore important to determine the ventilation strategy at an early stage of design to ensure that the systems are tailored to the requirements of each area. In practice this means that areas with specific requirements have dedicated air handling systems, and that departments occupied only during office hours are served by plant separate from that serving continuously occupied areas.

In general, separate ventilation systems should be provided for each department or group of similar departments provided that they are closely grouped together.

Each operating theatre suite should ideally be provided with its own plant but it is accepted practice to have a zoned common air handling unit serving two adjacent suites. There are many examples where common air handling plant has been provided for an entire operating department which, in the event of plant failure or maintenance shut-down, will render the whole department inoperative. Also, it means that it would be uneconomic to operate a single theatre for emergency or maternity use out of normal hours.

For health care buildings within the UK, it should not be assumed that the entire building needs to be closely temperature controlled. Ward areas (with the exception of isolation rooms and other special rooms) should be designed for natural ventilation unless situated in a noisy or heavily polluted location. Ancillary areas such as toilets, bathrooms, utility rooms, etc. should be provided with an extract system. It is a general requirement for health care buildings that the building has an overall positive or neutral pressure and the extracted air replaced by treated make-up air supplied to, for example, internal areas, staff base, etc. in ward areas.

2.3.13.2 Cleanliness and infection control

Ventilation systems should be of the all-fresh-air type to minimise risk of infection. In areas such as non-invasive imaging, equipment rooms and staff areas, local recirculatory air systems in the form of fan coil or split air conditioning units may be used, supplemented by primary air.

Air handling plant for all medical areas should be of the 'blow-through' type with only the frost coil and pre-filter upstream of the fan to ensure that there is no inward leakage of air downstream of the coils and main filter. Ventilation systems should be fully ducted. If contamination occured only the affected rooms and associated ductwork would require cleansing. With a return air ceiling plenum, access to the void above the room would be necessary for cleaning.

2.3.13.3 Ductwork and distribution

Ductwork systems should be low velocity designs to minimise fan power energy and noise. Attention should be given to eliminate cross-talk in areas where confidentiality is necessary or where patients may be noisy.

Ductwork systems should be cleaned on completion and provided with sufficient access points to ensure that adequate cleaning can be undertaken.

Air terminals should be selected with ease of cleaning as a primary consideration. Internal acoustic linings should be avoided. Room-side supply air attenuators as a minimum should be suitably lined to prevent fibre migration and to facilitate cleaning.

2.3.13.4 Ventilation system design

There are many mechanically ventilated spaces that do not require close control of temperature and where a summer upper limit of 25 °C will be acceptable. Ventilation systems should be designed with a small temperature difference between supply air temperature and room design temperature to achieve acceptable variation in room temperature for the majority of spaces, without the need for local temperature control.

As a general principle, space heating should be provided independently and not rely on adding heat to the ventilation supply air. However, in theatre suites and high dependency areas such as intensive care, heating requirements would normally be met by the ventilation system.

Most ventilation systems are constant volume type to satisfy pressure regimes or to offset fixed extraction rates. Variable air volume (VAV) systems may be appropriate for areas where cooling loads are variable. They will also be more energy efficient in these situations than constant volume systems.

Mechanical ventilation systems for hospitals and health care buildings need to be designed to meet the sound control requirements described in section 5. There is often a high proportion of rooms requiring full height partitions for fire compartmentation and acoustic separation and this requires that VAV systems have devices to balance both supply and extract to each area. This means that VAV systems are costly.

An economic case can be made for heat recovery on continuously operating ventilation systems. To avoid the risk of cross infection, air/water heat recovery systems are preferred and air/air systems would be subject to agreement with the infection control officer and would normally exclude dirty extracts.

In hospitals, the patients are dependent to varying degrees on the staff for evacuation in the event of fire. This, combined with various fire risk rooms, results in a higher than normal requirement for sub-compartments and compartmentation of risk rooms. It is therefore important to minimise the number of fire- and smoke-operated dampers by appropriate routing of ducts when compartmentation requirements are determined.

In many departments in hospitals, especially in operating departments and high dependency areas, the ventilation will need to remain operational in the event of fire when other areas would be under firefighters' control. In these circumstances, the ventilation system should shut down only in the event that smoke is detected in the supply air.

Mechanical ventilation systems for hospitals need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building. It should be noted that the external design conditions for health care buildings are more onerous than for other building types and summer/winter values are based on those not exceeded for more than 10 hours per year.

For specific ventilation requirements reference should be made to appropriate NHS Health Building Notes and Health Technical Memoranda, with particular reference to HTM 2025[110].

Ventilation rates for typical spaces are given in Table 2.23.

2.3.13.5 Humidification

It should not be assumed that humidification is required in all areas. The avoidance of infection and, in particular, *Legionellae* is of paramount importance, especially as many patients will have limited resistance. The recommended method of humidifying the supply air is by steam injection from plant steam (clean steam is not required). Electrical generation of steam is low in initial cost but high in running cost and should be avoided. Alternative methods of humidification would normally be subject to agreement with the infection control officer.

Table 2.23 Hospitals and health care buildings: ventilation rates

Space	Ventilation rate / air changes per hour
Toilets:	
— general	10
— en suite	6
Bathrooms:	
— general	10
— en suite	6
Dirty utility room	10
Changing rooms	5
Isolation rooms	10 (minimum)
Delivery rooms	10 (minimum)
Recovery rooms	15
Treatment rooms	6 (minimum to offset heat gain)

Table 2.24 Hospitals and health care buildings; filtration requirements

Application	Filter class*
Pre-filters on air handling plant, protection to heat recovery source coils	G3
Final filter for general spaces	F6
Final filter for clinical spaces; protection to HEPA filters	F8
Aseptic suite; sterile services department; operating theatre ultra-clean units	H10–H14

* See Tables 2.46 and 2.47 (page 2-120) for details of filter classes

2.3.13.6 Filtration requirements

Various levels of filtration performance are required, see Table 2.24.

2.3.13.7 Specialist areas

Certain areas have ventilation requirements that cannot be achieved by normal methods. These include audiology rooms where extremely low background noise levels must be achieved and aseptic suites where low particle counts are necessary. In these instances it is recommended that specialist contractors take responsibility for both the building enclosure and the building engineering services, including ventilation, within the enclosure.

2.3.14 Hotels

2.3.14.1 General

Hotels present a number of design challenges. Running costs are usually of high importance to the operator but the control of these should not affect guest comfort levels. Obtaining energy cheaply and using it efficiently are both areas that should be reviewed. Maintenance also needs to be carefully considered as many hotels have limited on-site technical support.

Guests directly paying for a service are reluctant to accept compromises in temperature, service or the quality of the environment that would allow the hotel to reduce its energy consumption. Therefore it is important to avoid waste. To achieve this, systems need to be responsive and readily controllable. Means to turn off, or turn down, systems when they are not required should be provided, but must be straightforward and easily managed by non-technical staff.

The level of service will depending on the type of hotel. Understanding the type and the branding of the hotel is important to choosing the right system. In the UK, standard solutions range from electric heating with natural ventilation to full air conditioning. Many hotel operators will have well-developed standard solutions. Different types of hotels will also have different occupancy rates and this can have a major impact on sizing of central plant and public space systems. A business hotel will have a full occupancy at between 1.1 and 1.3 persons/room whereas a family or resort hotel will have a much higher occupancy, typically up to at least 2.0 persons/room. A rate of 2.4 persons/room may not be unreasonable for a busy budget hotel near an airport.

2.3.14.2 Design considerations and strategies

There are three principal areas within a hotel: guest bedrooms (including en-suite bathrooms), public areas and 'back of house' areas. Each of these is serviced in a different manner and requires different operating schedules. The diversities applied to central plant can therefore be quite high and the likely peak loads need to be carefully considered. A spreadsheet showing the combined load at hourly intervals is an effective way of reviewing how the different loads interact and can be used in design discussions with the client. It can also be used as the first step in analysing the potential for a combined heat and power (CHP) approach. Hotels, particularly those with swimming pools, are usually good candidates for CHP.

Guest bedrooms

For an air conditioned hotel, a common approach is to employ a four-pipe fan coil unit located above the entrance lobby but it is also possible to locate the unit against the perimeter wall or above the bathroom, provided that adequate access is available for maintenance. The unit should be sized to allow a rapid and individual response to each room. Other common solutions are water source heat pumps and variable refrigerant flow (VRF) systems. These have the advantage of using less riser space but may require more maintenance. Care must also be taken with refrigerant systems to ensure that the effects of a refrigerant gas leak can be dealt with safely[111].

Environmental control needs to be clear and responsive. Controls should be simple to understand and to operate. Acceptable noise levels can also be an issue and need to be agreed with the client. A reasonable standard is to design for an overnight condition of NR30 on low speed and allow higher noise levels to meet the design load. Luxury hotels may require an overnight level of NR25.

Care should be taken not to oversize the selected system while ensuring that the system remains responsive. The peak solar load is unlikely to coincide with the peak internal loads. Depending on occupancy, a peak room cooling load between 1.5 and 2.0 kW will normally be adequate for the UK. For a well constructed and insulated building, the heat gains to a typical bedroom when occupied will offset the heat losses. Therefore heating costs can be low and a design can be developed that will provide the most effective and controllable means of meeting this intermittent low load. Some hotels have adopted electric heating because of the ease of control and the saving on installed cost.

Some hotels choose to limit the energy consumption of the bedroom systems by the use of occupancy detectors, key fobs or central booking systems. These can be used to turn off electrical systems and turn down the air conditioning when the guests are not in the room. This has been shown to make significant energy savings but care needs to be taken to ensure that guest comfort levels are not affected and that critical loads such as the 'minibar' (if present) are not isolated.

For compliance with building regulations, the minimum extract rate for a bathroom is 15 litre·s^{-1} but many hotels use higher values such as 25 litre·s^{-1}. This will provide 10 to 15 air changes per hour in the bathroom and balance the supply of fresh air for two occupants in the room. At these higher rates, tempered air is usually supplied directly to the room or to the fan coil unit within the room to avoid large gaps under doors or external air grilles. Some hotels choose even higher values to minimise condensation in bathrooms and improve air quality generally, particularly if smoking is allowed.

The supply location needs to be positioned to reduce the likelihood of draughts over the bed and in areas that may be used by the occupants when walking to and from the bathroom. The fresh air supply should be designed to take account of the fact that many UK guests will turn off the air-conditioning before going to sleep and this should not, ideally, limit the incoming fresh air. It is common to keep the bedroom supply and bathroom extract systems running continuously to maintain room air quality and to ensure adequate extract from the bathroom at unusual hours. Therefore heat recovery should be considered for these systems

Public areas

Public areas such as reception, conference, bar and restaurant areas are generally characterised by high, but variable, occupancy levels and lighting loads. The chosen system will need to be responsive and capable of delivering high quantities of fresh air when required to do so. This will often suggest all-air systems but these need to be carefully zoned to allow individual control of spaces. Where possible, separate systems for the different areas are ideal, but multi-zone systems are also used and these are sometimes supplemented with fan coil units to provide more individual control. Constant volume systems with reheat are occasionally used but can be wasteful of energy. VAV systems are also used but should be treated with care to ensure that adequate fresh air is delivered to the space under all conditions.

The design of the systems for the public areas will need to achieve criteria imposed by licensing regulations. The level of occupancy to which the hotel wishes to be licensed should be agreed with the client at an early stage to ensure that the air systems will be capable of delivering the correct fresh air quantities to meet the requirements of the licensing authority. Typical design occupancies range from 1 person per 1.2 m^2 for 'theatre' style conference rooms, to 1 person per 2 m^2 for bars and restaurants and 1 person per 4 m^2 for reception and entrance areas. These figures should be confirmed at an early stage as the operator may wish to have the hotel licensed for higher densities. The fresh air quantities should allow for some smoking but not necessarily at the peak occupancies quoted above.

'Back of house' areas

The 'staff only' areas will require a variety of systems to suit their different uses. Typically, these areas will include managers offices, kitchens, laundries or linen handling, staff changing, staff dining, training, IT and computer rooms. Reference should be made to the guidance given for kitchens (section 2.3.6.1) and computer rooms (section 2.3.9).

The general office areas will normally be treated to the same level as the public spaces, (i.e. for an air conditioned hotel they will be air conditioned). Some hotels believe in extending this to cover further areas, such as the staff dining rooms and this needs to be clarified with the client as early as possible. It is common for the kitchens to be cooled, at least in part, so that salads, pastries and deserts can be well presented.

Many hotels contract-out their laundry, but linen handling space will still be needed. These areas require high air change rates to remove the high levels of dust and lint that will be generated during sorting. A figure of 15 air changes per hour may be considered as reasonable. Linen chutes will also generate high dust levels in the collection room.

Increasingly, hotels have sophisticated billing systems and therefore the computer room housing the central IT equipment must be properly conditioned.

2.3.15 Industrial ventilation

2.3.15.1 General requirements

In an industrial context, ventilation is usually employed to remove airborne contaminants arising from processes or machines. Satisfactory ambient conditions can be achieved by dilution where contaminant sources are weak, of low toxicity, and are either scattered or mobile. However, it is usually more appropriate to remove the contaminant at, or close to, its source by means of local exhaust, e.g. vehicle exhaust removal systems in garages.

Sources of industrial contaminants often require large extract airflow rates to ensure that the released pollutant is effectively captured and conveyed away by the extract system. In such cases, particular attention should be paid to ensuring adequate replacement or make-up air. It may be necessary to directly heat the incoming air in winter or, in order to reduce the resulting high energy consumption, to duct the outdoor air directly to the source location.

Certain processes, such as paint spraying may require filtration of the incoming air. Similarly it may be necessary to remove the contamination from the exhaust air before it is discharged to outside. Special industrial air cleaning devices are available for this purpose, see section 2.5.4.

The basic factors that affect the choice between natural and mechanical ventilation are:

— quantity of air required
— quality of air required

— consistency of control required

— isolation required from external environment.

It is almost certain that mechanical ventilation will be necessary given the likelihood of high airflow rates and the need to treat the incoming air, i.e. by heating, cooling, or filtration. Mechanical ventilation systems can be designed to provide constant or variable flow rates distributed as required throughout the building. When a building is located in a noisy environment, it is often impracticable to provide adequate natural ventilation without excessive sound transmission through the openings. In such circumstances, mechanical ventilation systems with appropriate acoustic treatment can be used. Mechanical ventilation can also be designed to control room pressures to prevent the ingress or egress of contaminants.

Ideally, industrial ventilation systems should limit the exposure of workers to airborne contaminants to zero, or as near zero as is practicable. As a minimum, limits should be maintained below the most recently published occupational health limits[43]. These are updated annually and it is essential that current information be used.

If extract rates are too low, short term or long term damage to health will occur or, at the very least, serious discomfort will be experienced. If too much air is handled, fan and ductwork costs (both capital and running) are excessive, incoming air treatment costs are high, draughts may be difficult and expensive to prevent, and the industrial processes may be affected by overcooling or costly increases in chemical evaporation rates.

The most effective method of preventing a contaminant from entering the breathing zone of a worker is to isolate the process by total enclosure. This solution is essential where highly toxic substances are involved and may be appropriate for automated processes. Normally some degree of access to the process will be required. It is desirable to limit this access to the minimum necessary for a particular process e.g. access to a low emission chemical process within a fume cupboard via a sliding door, to components to be welded together, or to surfaces to be spray painted. In all cases the contaminant must be drawn away from the breathing zone of the worker.

Guidance on achieving energy efficient ventilation design within industrial buildings is available from BRECSU* and, for industrial processes, by ETSU† under the government's Energy Efficiency Best Practice programme.

2.3.15.2 Exhaust hood suction dynamics

The velocity of the air induced by suction at an exhaust hood decreases rapidly with distance from the opening. In theory, the velocity at a given distance from an opening can be predicted from an equation of the form:

$$V_x = \frac{Q}{B\,x^n + A} \qquad (2.4)$$

*Building Research Energy Conservation Support Unit (BRECSU), Garston, Watford WD2 7JR, UK (www.bre.co.uk/brecsu/index.html)

†Energy Technology Support Unit (ETSU), Building 156, AEA Technology plc, Harwell, Didcot, Oxfordshire, OX11 0RA, UK (www.etsu.com/eebpp/home.htm)

where V_x is the air velocity at distance x from the opening ($m \cdot s^{-1}$), Q is the volume flow rate of air ($m^3 \cdot s^{-1}$), x is the distance from the opening (m) and A, B and n are constants depending on the geometry of the opening and the flow characteristics. Values for these constants are usually obtained experimentally.

Figure 2.9 shows solutions of this equation for circular openings having unflanged and flanged edges. Note the improvement in performance when the suction is focussed by the flange. The efficiency of capture can be further improved by side screens which also reduce the influence of cross draughts. The ultimate extension of this principle is to enclose the process completely. Velocities are given as percentages of velocity at the opening V_o. Distances from opening are given as percentages of the diameter, d.

Solutions to equation 2.4 for various types of openings are given section 2.5.4.

The momentum of the air induced by suction at an opening must be sufficient at the part of the process most remote from the opening to overcome a combination of the following forces:

— *gravitation*: due to the density of the air/contaminant mixture in relation to the surrounding air

— *friction*: to overcome drag on the mixture due to the neighbouring bulk of room air

— *dynamic*: due to the initial momentum of the contaminant on release from source and/or disturbing forces due to movement of room air, e.g. cross draughts.

Gravitational and dynamic forces may be used to assist capture. Heavy dust particles having some momentum should be directed into an opening close to the source and, ideally, should be collected and removed from the exhaust without further transport. Transporting large particles through a duct requires very high velocities.

If emitted into a workspace with low momentum, the concentration of contaminant immediately adjacent to its source will be high but normally complete mixing with workspace air will occur within a short distance from the source. An obstructed bayonet plume from a hot source will entrain and mix with room air thus expanding the plume, but if an opening can be used to contain the

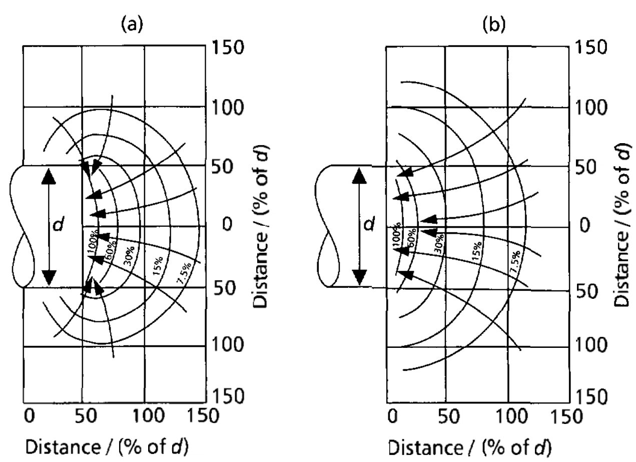

Figure 2.9 Isovels for circular openings; (a) sharp edged opening, (b) flanged opening

plume, induction may prove sufficient to avoid the need for additional fan-induced forces.

2.3.15.3 System design

Individual exhaust hoods can be either discharged separately to outside via individual fans, or connected via a multi-branch system to central fan(s) depending upon:

— compatibility of substances evolved by different processes; if in doubt, use separate exhausts

— access to the outside wall: multiple roof penetration might not be acceptable

— aesthetics of multiple discharges

— potential for air cleaning and recirculation of heat recovery from exhausts (see section 2.5.4)

— balancing: multi-branch dust handling systems must be self-balancing, obstructions within duct work could create blockages

— process usage pattern: ventilation may need to be isolated when a process is not in use and operation of an isolating damper may upset system balance unless a variable volume fan is used; (the VAV fan would be controlled from a system pressure sensor, which could become blocked if dust is transported within the duct).

If make-up air requirements are small they can be drawn from outside or surrounding areas via cracks or openings in the fabric. However, negative pressure must not be allowed to develop at a level at which swing doors are held open or cold draughts are produced in occupied spaces near doors or windows etc. Careful positioning of perimeter heating will minimise discomfort by warming the incoming air. If make-up is too low, the performance of one hood may be affected by the operation of other hoods.

It is preferable to supply the make-up air via a handling system, which cleans, heats (in winter) and, exceptionally, cools and dehumidifies the air, as appropriate. Large volumes of make-up air may be required. This has considerable implications for energy consumption, therefore consideration must be given to:

— supply of tempered make-up air direct to the process (e.g. by push-pull system)

— partial recirculation of exhaust air after removal of contaminant using high efficiency air cleaning(112), see section 2.5.7

— recovery of heat from exhaust to incoming make-up air but avoiding transfer of contaminants, see section 2.5.6.

Make-up air must be supplied into the space in such a way as to avoid causing draughts across the process, which would affect the efficiency of capture.

2.3.16 Laboratories

2.3.16.1 General(113)

The design of laboratory projects will generally be biased towards the design of the ventilation systems for (*a*) fume control, (*b*) containment, or (*c*) providing specific close environmental conditions for either animal welfare or research processes.

The choice of protection to be provided will need to be identified by the client or end user as part of their safety assessment of the work undertaken. Operator protection may be provided by fume cupboards, microbiological safety cabinets or other local exhaust ventilation systems.

The design of laboratories will need to take many factors account, including the following:

— number of fume cupboards, their performance criteria and diversity of use

— number of microbiological safety cabinets

— local exhaust ventilation systems

— minimum ventilation rates to dilute odours and contaminants

— pressure differentials or air flow direction with respect to adjacent spaces

— temperature criteria and heat gains

— filtration standards

— standby capacity

— plant space

— fume discharges to atmosphere

— ductwork materials

— running costs.

Mechanical ventilation systems for laboratories need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building.

Information on the design of laboratories is available within the series of *Baseline Guides* produced by the International Society for Pharmaceutical Engineering*.

2.3.16.2 Design requirements and strategies

Fume cupboard installations

The performance criteria for the fume cupboard will need to be established by the end user and will be a function of face velocity and containment factors. Generally good containment can be achieved at face velocities of 0.5 $m \cdot s^{-1}$ and may still be achieved at lower face velocities depending on the design of the fume cupboard. The face velocity and containment factor are normally specified in accordance with a sash working height of 500 mm. The specification of lower face velocities should be in conjunction with suitable type testing conditions and agreement to containment levels necessary to suit the end user's activities. Higher face velocities may be required for radioactive work but velocities exceeding 0.7 $m \cdot s^{-1}$ can create turbulence around the operator that may affect the containment performance of the fume cupboard.

*International Society for Pharmaceutical Engineering, 3816W Linebaugh Avenue, Suite 412, Tampa, Florida 33624, USA (www.ispe.org)

A minimum air change rate in a mechanically ventilated laboratory may be set between 6 and 15 air changes per hour, depending on the type of work that is being undertaken and the need to remove or dilute odours. Where fume cupboards are installed the face velocity may dictate the amount of air to be extracted and supplied, and this may exceed minimum ventilation requirements.

Where single or a small number of fume cupboards are installed, then constant volume 'face and bypass' fume cupboards may be considered with the fume cupboard acting as the return air path for the room.

Where large numbers of fume cupboards are to be installed then variable volume ventilation systems should be considered. Such systems enable a diversity in use to be applied and hence the size and cost of central plant can be reduced compared with that required for constant volume systems. In addition to the energy savings realised, the increased capital cost of the controls can be offset by the reduced costs of central plant and reduced plant room space requirements. The primary energy saving is achieved by the ability to deliver and extract reduced quantities of air. Central plant diversities of 50–70% can be applied to large installations. The diversity should take into account the number of fume cupboards in the laboratory, the number of users, and the type of work being undertaken. It may be appropriate to undertake studies to this effect, which may lead to lower diversities being applied.

Central extract systems will need to take account of the requirements for discharge of fumes via flue stacks. To achieve suitable dispersal of fumes the discharge velocity should generally not be less than 15 $m \cdot s^{-1}$. With variable volume systems consideration should be given to providing automatic make-up air controls to collector ducts, in order to maintain discharge velocities. Flue stack heights may be in accordance with BS 7258[113] or can be determined by wind tunnel testing or dilution and dispersal calculations.

The use of individual extract fans may be appropriate if the fume cupboards are dispersed around the building in a way that would preclude the installation of a common collector duct.

Microbiological laboratories[114]

The design of laboratories for work on biological agents requires attention to the following particular factors:

- containment category
- number, size and class of safety cabinets
- operational requirements of the laboratory
- standby plant
- pressure differentials
- location/safe change requirement for HEPA filtration
- fumigation and sterilisation procedures
- safe access for maintenance of filters and other areas of potential contaminant concentration.

Guidance from the Advisory Committee on Dangerous Pathogens[115] defines hazard groups and provides recommendations for containment levels for laboratories and animal rooms along with appendices providing useful information and recommendations. Table 2.25 summarises the requirements and recommendations for laboratory containment.

The containment levels are as follows:

- *Containment Level 1*: suitable for work with agents in hazard group 1, which are unlikely to cause disease by infection, some agents in this group are nevertheless hazardous in other ways, i.e. allergenic, toxigenic etc. It is preferable to maintain an inward air flow by extracting room air to atmosphere.

Table 2.25 Summary of laboratory containment requirements and recommendations

Measure	Requirement for stated hazard level			
	None	Low	Medium	High
ACDP containment level	1	2	3	4
Isolate from other areas	No	No	Yes/partial	Yes
Air lock	No	No	Optional (self closing) shower	Yes, via air lock and interlocking outer and inner doors; provide
Sealable for decontamination	No	No	Yes	Yes
Inward airflow/negative pressure	Optional	No, unless mechanically ventilated	Yes; –30 Pa in laboratory	Yes; –70 Pa in laboratory; –30 Pa in air lock; alarm system required
Supply filtered	—	Yes	Yes	HEPA filtered
Monitor air pressures	—	No	Yes, on supply	Yes
Effluent treatment	No	No	HEPA filtration of extract air	Double HEPA filtration of extract air, treatment of liquid waste and solid waste
Microbiological safety cabinet/enclosure	No	Yes, where airborne hazard	Yes	Yes
Safety cabinet class (user defined)	—	Class I	Class I, II or III	Class III
Autoclave site	—	In suite	In suite	In laboratory, double ended
Emergency shower	Agree with users	Preferred; agree with users	Yes	Yes

— *Containment Level 2*: suitable for work with biological agents in hazard group 2. Restricted access required. Maintain at a negative air pressure and keep doors closed while work is in progress.

— *Containment Level 3*: suitable for work with biological agents in hazard group 3. The laboratory to be separated from other activities in the same building with access restricted to authorised persons. The laboratory is to be maintained at a negative air pressure generally only when work with biological agents is in progress, although some clients may require pressure differentials to be maintained continuously. Extract must be HEPA filtered. The laboratory is to be sealed for disinfection, which may require gas-tight shut-off dampers on ductwork systems and sealed fittings and services penetrations. Ventilation systems should also incorporate a means of preventing reverse air flows. Design of systems to achieve the required inward airflow should aim for simplicity.

— *Containment Level 4*: suitable for work with biological agents in hazard group 4. Maintain at a negative air pressure. Input air to be HEPA filtered, extract air to be double HEPA filtered.

Hazardous work within the laboratory will generally be undertaken in microbiological safety cabinets. Safety cabinets provide protection against dangerous pathogens. There are three classes of safety cabinets:

— *Class 1 safety cabinets*: provide user protection. The cabinet has a through flow of air and incorporates an integral HEPA filter. A variable speed fan is provided in the extract ductwork to overcome the changing resistance of the filter. Suitable for use with hazard groups 1, 2 and 3.

— *Class 2 safety cabinets*: protect the operator and the work by recirculating some of the air through a HEPA filter to provide a down-flow over the working area. An integral variable speed fan is provided to overcome the changing resistance of the filters. The main extract fan in the exhaust duct may require to be either variable or constant volume, depending on the manufacturer. Class 2 safety cabinets are divided into two types: high protection, for use with groups 1, 2, and 3; low protection for use with hazard groups 1 and 2.

— *Class 3 safety cabinets*: totally enclosed units designed to provide a high degree of user protection. Air is drawn in and exhausted via HEPA filters. The operator uses gloves to manipulate experiments. Suitable for hazard groups 1 to 4.

2.3.17 Museums, libraries and art galleries

2.3.17.1 General

Most buildings control their environment for human health and comfort reasons during periods of occupation. However, buildings used for the display or storage of objects, books and documents requiring long-term preservation must be kept within appropriate relative humidity and temperature ranges 24 hours a day so as to minimise damage to the collections they contain.

Historic materials are vulnerable to:

— physical damage, due to expansion and shrinking

— chemical deterioration, due to corrosion in damp conditions or by pollutants

— bio-deterioration (destruction by moulds or insects)

Damage is caused by atmospheric moisture, heat, direct sunlight, ultraviolet radiation, and external and internal atmospheric contaminants. It is most often a combination of these factors that causes significant damage.

2.3.17.2 Design considerations

Different materials may have their own distinct requirements. This means that conditions within a building may need to vary in different locations to suit their specific requirements. Since objects, books and archives may be added to, changed or re-organised, it is important that allowance be made in the design for varying the conditions within the space in order to match changing needs. This must be commensurate with sound energy-efficient practice.

The particular physical condition of objects or groups of objects may necessitate different environmental conditions. Therefore specific ranges of relative humidity for the conservation of historic materials can be decided only in discussion with whoever is responsible for their physical well-being, usually a conservator. When this does not take place, the design is often based on idealised ranges that may be inappropriate.

Seasonal differences in the moisture content of fresh air need to be considered when determining the appropriate level of ventilation air; for instance, in winter external air often has a lower moisture content than in summer. While fresh air ventilation is necessary for human respiration, historic materials may also require air to be replenished in order to reduce the concentration of contaminants from off-gassing materials. This needs to be balanced against the potential for transporting harmful external pollutants into the building by ventilation. If mechanical ventilation is fitted, the use of particle and gaseous filtration is recommended for historic materials vulnerable to external pollutants that are likely to be of high concentration in urban locations. It is advisable for mechanical ventilation to be controlled by carbon dioxide sensors in order reduce the fresh air supply to the minimum requirement.

Materials such as paper, parchment, textiles, leather and wood may be kept within the broad range of 40% to 65%. However, the rate of change must be controlled because maintaining a stable relative humidity is more important than an actual set point within the range.

Metals and minerals benefit from an RH level below 50%, while bronze and glass should be kept below 40% RH. In areas where large numbers of people may congregate, it is important to consider that while the human comfort RH range of 40% to 60% may be suitable for most materials, those that require drier conditions may need to be displayed or stored within microclimates.

For room temperature, the range 18–24 °C, which is acceptable for human comfort, is also acceptable for historic materials. However, where materials have become acclimatised to a more elevated temperature, active cooling should only be considered after discussion with the conservator and, if appropriate, the conservation architect. Temperatures lower than 16 °C may be desirable for some materials such as photographs and film or where the temperature may be designed to vary in order to maintain a stable relative humidity.

2.3.17.3 Environmental control

Typical means of achieving controlled conditions in other building types can also be used in museums, libraries and archives. These are close control air conditioning, the use of dessicant or refrigerant rehumidifiers and, where conditions become too dry, humidifiers. Conservation heating is specific to environmental control in historic buildings. However this strategy is more appropriate to spaces where human comfort conditions are not required throughout the year. Conservation heating consists of control of heating systems with humidity and temperature sensors to provide environmental conditions for long-term conservation of objects, books and documents. Indoor relative humidity may need to be reduced at any time of the year, so the control systems should be set up to operate continuously.

Typically, a conservation heating system will maintain room temperatures 3–5 °C above their 'unheated' level in winter. This is in contrast with domestic winter heat input, which is designed to provide an average temperature increase of 8–10 °C. In good summer weather, there may be no call for corrective action for weeks on end, but weather changes can quickly produce damaging humidity conditions. Monitoring shows that the total heat input during the summer is small but important. This low level of heat input means that energy consumption is significantly lower than that for domestic heating systems. Depending on the size of the space to be controlled, solutions may vary from a single humidistat-controlled electric radiator to full multi-zoned schemes with computer building management systems.

Human beings do not generally notice changes in relative humidity, therefore locations with historic materials should be provided with instrumentation for the monitoring relative humidity and temperature.

Mechanical ventilation systems for libraries need to be designed to meet the sound control requirements in section 5 of this guide.

2.3.18 Plant rooms

Plant areas should be ventilated as necessary to ensure the correct operation of equipment and the safety, health and comfort of personnel.

2.3.18.1 Boiler rooms

Boiler rooms and other spaces containing fuel-burning appliances must be supplied with adequate fresh air to meet the requirements for combustion and to prevent overheating of the space. Compliance with the regulations governing the ventilation of such appliances must be maintained. Details are given in relevant Building Regulations Part J[38], British Standards e.g. BS 6798[55], BS 5410[56] and BS 5440[57]. Reference should also be made to section 1 of this Guide.

Rooms containing a gas installation should be ventilated to prevent the accumulation of gas as could occur from minor leaks. Ducts containing gas pipework should be ventilated to a safe position, preferably direct to outside air. Measures for routing pipework may include enclosing the pipework in a ventilated gas-tight sleeve ('pipe-in-pipe'). It should be ensured that ventilation arrangements do not impair any provisions for fire/smoke separation. Refer to Gas Safety Regulations[116], Council for Registered Gas Installers (CORGI) and Institution of Gas Engineers[117] for guidance.

Oil tank chambers should be ventilated to the open air to prevent stagnation, independently of any other portion of the premises and preferably by natural means.

2.3.18.2 Refrigeration plant rooms

Refrigeration plant rooms should be provided with ventilation as required for the safety, health and comfort of personnel and for emergency purposes in the event of a major leak. Reference should be made to BS 4434[116].

2.3.18.3 Battery rooms

Depending on type of batteries present, ventilation should be provided so that any potentially explosive gaseous mixtures are dispersed safely below non-hazardous levels. Battery life can also be reduced by high continuous space temperatures, e.g. temperatures greater than 25 °C[116].

2.3.18.4 Electrical plant rooms

Particular care should be taken to ensure adequate ventilation for rooms containing electrical plant to prevent build-up of heat generated by the equipment.

These include the following:

- IT, communications rooms and incoming frame rooms that have active heat generating equipment
- transformer rooms
- electrical switchrooms
- uninterruptable power supply (UPS) rooms.

2.3.18.5 Water storage areas

Storage temperatures should comply with the requirements of the Water Regulations[119,120] and CIBSE and HSE recommendations concerning the growth of *Legionella*[121,122].

2.3.18.6 Lift motor rooms

Reference should be made to CIBSE Guide D[123].

2.3.19 Schools and educational buildings

2.3.19.1 Schools

General

The Department for Education and Skills's *Guidelines for Environmental Design in Schools*[124] recommend that, as far as possible, school buildings should be naturally ventilated. Exceptions are WCs, changing rooms, craft design and technology areas, kitchens, laboratories and other special activity areas where contamination or high heat gains might occur that may require local or other mechanical ventilation.

Requirements

Table 2.26 lists some required ventilation rates drawn from the Schools Premises Regulations[125].

(*a*) Airtightness

A level of airtightness for schools is not specified although a maximum of 0.3 ACH has been suggested[126]. This is required to minimise heat losses when unoccupied.

(*b*) Air movement

Air movement at the level of the occupant must be at a temperature and velocity to ensure comfort. Natural ventilation should therefore be controllable to allow users to adjust the ventilation rate as required. Adjustments should be achieved by the appropriate use of window types and opening sizes, including trickle ventilators. Ideally openings should be provided in more than one face of each room to maximise cross ventilation. Guidance is available on the passive solar design of schools to facilitate solar-induced stack effect to encourage ventilation on days with little wind[127]. Passive stack enhancement may also be considered. Particular care should be taken to ensure that any odours arising from the use of volatile organic compounds (VOCs) during construction work, or arising from school activities, can be dealt with.

(*c*) Make-up air

Make-up air may be taken from surrounding spaces if this will not increase ventilation rates in teaching spaces beyond that required, in which case a secondary supply of fresh air may be provided.

(*d*) Window selection

Sash windows are often used in schools because they provide high and low level openings, thereby giving occupants a considerable amount of control. However, only 50% of their area is available for ventilation. Side-hung casement windows give a greater openable area but care must be taken to ensure that they do not present a safety hazard when fully open[126]. In upper stories, the opening of windows is often restricted to minimise the risk of children falling out.

(*e*) Atria

Care should be taken with the design of atria within schools premises, which may be provided as low cost teaching space and buffer zones to classrooms. Ventilation provision must be sufficient to prevent overheating without compromising acoustic separation[126].

(*f*) Draught lobbies

Effective draught lobbies should be specified where possible to minimise the amount of disadvantageous ventilation caused by occupants moving in and out of the building[126].

Further considerations

The Department for Education and Skills (DfES) has embraced the concepts of environmental assessment of its premises. It places emphasis not just on energy use but also on ease of maintenance. Guidance can be found in DfES publications[124,131]. Designers can gain credits by:

— demonstrating due consideration to the provision of ventilation (including the client and user in the development of the design with regards to risk assessment)

— the timely provision of completed record drawings and operation and maintenance (O&M) manuals

— the provision of training on the operation of any controls to the caretaker.

Table 2.26 Required ventilation rates in schools premises

Area	Ventilation rate	Notes
General teaching areas	3 litre·s^{-1} per person as minimum	
	8 litre·s^{-1} per person for rapid ventilation by opening windows or vents	Ventilation systems, whether natural or mechanical, should be capable of providing approximately 8 litre·s^{-1} per person of fresh air in all teaching areas medical examination or treatment rooms, sleeping and living accommodation
		Adequate measures should be taken to prevent condensation and remove noxious fumes from every kitchen and other room in which there may be steam or fumes.
		Guidance specific to the education sector with regards to health and safety issues as described in the Workplace Regulations[103] has been produced by the HSE[128]
Laboratories	—	To satisfy COSHH requirements[42] and DfES guidance on fume cupboards[129]
Wash rooms	6 ACH minimum	
Swimming pools	—	Refer to specialist guidance[130] and section 3.21.7

2.3.19.2 Higher education premises

Residential accommodation

Developments in the UK have demonstrated the potential for low energy residential accommodation, both through high levels of insulation and mechanical ventilation with heat recovery[139] or through passive ventilation via trickle ventilators and local mechanical extract where required[84].

Lecture theatres, study areas and design studios

Occupancy patterns can be dense but intermittent, or extended but sparse. Environmental control tends to be remote from the individual occupants. Teaching spaces designed to serve more than 100 people usually require some form of mechanical ventilation, although this may be as part of a mixed mode approach e.g. punkah fans within ventilation stacks. High levels of thermal mass and night cooling can also be effective in reducing energy demand. Control of airflow rates can be achieved through CO_2 sensors to establish a minimum rate. Care must be taken in the case of naturally ventilated solutions to avoid noise problems from external sources.

The breadth of design options for innovative low energy designs is illustrated in case studies by BRECSU[133–135] and the Higher Education Estates Department*.

Specialist areas

Guidance on suitable treatments for other types of space found within higher and further education premises such as laboratories, learning resource centres, swimming pools, catering facilities can be found elsewhere in section 2.3.

2.3.20 Shops and retail premises

2.3.20.1 General

The general aim of the ventilation and air conditioning strategy is to provide a comfortable environment within the occupied zone. This is achieved by providing fresh air for the customers and staff and the removal of the heat from the space which arises from lighting, equipment, solar and occupancy gains.

2.3.20.2 Design requirements

The temperature within the space will vary according to season but is typically 18–22 °C depending on the requirements of the retailer. The upper limit may be permitted to rise in summer to prevent an unacceptable temperature differential between the retail space and the circulation space outside (i.e. outside or covered mall).

Minimum fresh air should be provided to satisfy occupancy loads based on the client's requirements or Building Regulations Approved Document F[37], whichever is the greater. Fresh air is typically introduced at a minimum rate of 5 $litre{\cdot}s^{-1}$ per person. This rate is lower than the minimum stated in Building Regulations of 8 $litre{\cdot}s^{-1}$ per person, which is for an occupiable room that is defined as not including a shop or circulation space. These require a minimum of 1 $litre{\cdot}s^{-1}{\cdot}m^{-2}$. The typical minimum fresh air rate is based on a typical occupancy of 1 person per 5 m^2. This fresh air rate is for a retail area in which smoking is not permitted. Minimum fresh air for occupation is supplied to the space via a supply AHU or via an extract fan in conjunction with openings on an external wall.

Heat gains will be a function of the building and the specific application but will often be characterised by one or more of the following:

- transient occupancy with high peak value
- high solar gains local to large areas of glazed shop front
- high lighting gains for display purposes
- localised equipment loads, e.g. hot food counters.

Infiltration of air from the outside due to door opening can be a particular concern. The problem may be exacerbated if there are openings on opposite facades of a store encouraging cross-ventilation driven by wind or stack forces (e.g. if opening onto a shopping mall). Locating openings on a single façade will help to balance these forces. Draughts within stores caused by infiltration can be minimised by the sealing of the building structure or the use of lobbies on entrances to deflect/direct airflow.

2.3.20.3 Strategies

Ventilation and air conditioning of the space can be achieved by various methods using centralised or unitary equipment. The choice of plant is governed by the retailer's particular requirements, the availability of external plant space, the size of the retail space and the availability of services supplied by the lessor.

Systems served by centralised plant can take the form of displacement or constant volume systems, both using recirculation or free cooling to provide the volume necessary to enable distribution of conditioned air at an acceptable temperature. Examples of minimum fresh air systems include unitary cooling split DX air conditioning or 2- or 4-pipe fan coil units.

Consideration should be given to recovery of heating/cooling energy that would normal be rejected. The ventilation system design may allow for the integration of air-to-air heat recovery devices, which transfer heat from the exhaust air stream to allow fresh air inlet. Waste heat from air-cooled condensers used in the refrigeration process may be recycled and utilised to reduce the load on space-heating plant. Cooling recovery at low level using spilled air from display cabinets may be recycled and introduced to cold stores etc, reducing the loads on cooling plant.

It is now common for major outlets to be provided with a water loop for the air conditioning system. This provides users with the flexibility to provide their own heat pumps as necessary to meet their individual requirements. This type of system may also balance well with the diversity of activities undertaken by the occupier, often requiring simultaneous heating and cooling. Water source heat pump systems are well to meet such requirements.

*Estates Team, HEFCE, Northavon House, Coldharbour Lane, Frenchay, Bristol BS16 1QD (www.heestates.ac.uk)

Leakage and build-up of refrigerant in a public space can be a danger to health due to decomposition products from smoking or naked flames in the presence of certain refrigerants. The occupier should prepare an emergency procedure to be followed in the event of leakage. BS EN 378[111] should be consulted for guidance on procedures.

Ventilation rates within constant volume systems can be controlled using CO_2 or air quality sensors. Temperature control of central systems should be averaged where possible either using space sensors or a duct-mounted sensor in the extract system. Temperature control of unitary systems should be by individual or group controller, depending on the number of systems.

The building should be maintained under positive pressure by ensuring that the rate of supply exceeds the rate of extract. Extracts should be positioned in the areas of high heat gain, e.g. lighting displays or hot food counters.

For food stores, the type and performance of refrigerated display cases will influence the design of the ventilation and conditioning system in a number of ways:

- Display cases may require temperature and humidity levels within the space to be maintained below maximum limits.
- Losses from display case will locally cool the space.
- Display cases with integral heat rejection will provide a net heat input to the space.
- The performance of display cases is susceptible to draughts from doors and ventilation systems.

Losses from display cases can vary quite significantly, depending on case design. Refrigerated areas commonly require heating throughout the year. The losses can lead to a 'cold aisle' effect in refrigerated areas of a store. One means of reducing this effect is by recovering some of the cold air spilt from the display cases, which may then by used to cool other areas of the store via the ventilation system.

Some display cases reject heat to the space, rather than to external heat rejection plant via a refrigeration system. Such display cases will impose a net heat gain on the ventilation system.

Internal draughts into cases from the ventilation system are avoided by the careful positioning of supply points from the ventilation and air conditioning equipment.

Smoke extract from retail units may be installed as separate stand-alone systems, which act as additional safety ventilation systems, or be incorporated into the general ventilation systems which serve the retail unit (known as 'dual purpose'). There are three possibilities in smoke extraction design each with a different purpose:

(*a*) *Life safety*: systems designed to maintain tenable conditions on escape routes and other occupied areas.

(*b*) *Firefighting access/property protection*: systems designed to increase visibility for, and reduce heat exposure to, trained firefighters. This allows earlier and less hazardous attack on the fire. Such systems will help to reduce property damage by increasing fire brigade effectiveness.

(*c*) *Smoke purging*: systems designed to enable smoke to be cleared from a building after a fire has been brought under control.

It is necessary to decide which, or which combination, of these three objectives is to be achieved before commencing a design. BRE Report BR 368[70] should be consulted, in conjunction with BS 5588: Parts 9, 10 and 11[136].

2.3.21 Sports centres

2.3.21.1 Ventilation requirements

The recommended environmental conditions and ventilation rates for sports centres vary according to the activities being undertaken, see Table 2.27.

2.3.21.2 Multi-purpose halls/facilities[138]

Ventilation is required to remove players' body heat and odours, supply fresh air, keep spectators cool, maintain comfortable summertime conditions and prevent condensation. If the facility is also to be used for public entertainment, the relative importance of these functions depends on the activities taking place in the hall and the number of people present.

The ventilation system should be designed for controlled ventilation rates that can vary according to the occupants' needs at any given time, without introducing large volumes of cold air into the space that may cause discomfort and high heating loads.

For badminton, a draught-free playing area should be provided with air velocities less than 0.1 $m \cdot s^{-1}$ to prevent deflection of the shuttlecock. The location of inlet and extract grilles and openings must also be considered with regards to the flight paths of the shuttlecocks[139].

Table 2.27 Environmental conditions for sports centres[137]

Facility	Temperature / °C	Ventilation
Multi-purpose centre:		
— sports activities	12–18	8–12 $litre \cdot s^{-1} \cdot person^{-1}$
— sedentary activities	18–21	8–12 $litre \cdot s^{-1} \cdot person^{-1}$
Fitness centres	16–18	10–12 ACH
Weight training	12–14	10–12 ACH
Squash courts:		
— courts	16–18	4 ACH
— spectators	18	4 ACH
Ancillary halls:		
— sports	15	1.5 ACH
— non-sports	21	3 ACH
Changing rooms	20–25	10 ACH
Reception, administration and circulation spaces	16–20	Up to 3 ACH
Crèche	21	Up to 3 ACH
Refreshment and bar areas	18	Not less than 8 $litre \cdot s^{-1} \cdot person^{-1}$*
Swimming pool	27–31†	4–6 ACH 8–10 ACH if extensive water features

* Consult local licensing authority
† At least 1 K above water temperature

2.3.21.3 Fitness suites and weight training facilities

Effective ventilation is usually the most critical factor because of the metabolic heat gains, body odour and humidity that can rapidly occur in such spaces. Air conditioning is sometimes used but alternative, less energy-intensive approaches should be considered.

Special considerations may need to be made for spas, saunas, and solaria.

2.3.21.4 Squash courts

Squash courts should be well ventilated to keep walls free from condensation and remove the players' body heat, which can be considerable. Incoming air must not be drawn from changing rooms, bar areas, showers or any other parts of the building with high humidity levels.

In general, each court should have an extract fan centrally placed at high level. Fresh air can be drawn in through airbricks behind the playboard. This should be perforated to provide 10% free area.

Extract fans should over-run for 15 minutes after the courts have been vacated to ensure that all stale air has been removed. Fans should be linked to the court lighting circuit where practicable. The rate of ventilation in the spectator gallery may have to be based on maximum occupancy.

2.3.21.5 Ancillary halls

Ancillary halls may be used for a variety of both sporting and social activities, including public entertainment. Therefore the range of potential activities should be confirmed with the client prior to finalising the design of the ventilation system. A wide range of air change rates may be required, e.g. to remove smoke and ventilate the space for discos and dances. Consultation with the local licensing authority may also be necessary if the hall is to be used for public entertainment.

2.3.21.6 Changing rooms

These normally require a mechanical supply and extract system in larger facilities. In small facilities, satisfactory conditions may be achieved with conventional radiators and convectors combined with natural ventilation or local extract fans. The high fresh air requirement offers the opportunity for heat recovery to be cost effective.

2.3.21.7 Swimming pools

The recommended pool water temperature varies depending upon the activity. For competition swimming the pool is held at 26 °C. For leisure use a temperature range of 28–30 °C is more appropriate; for spas, remedial and other hot pools a pool temperature of 36 °C may be maintained. The air temperature in the pool hall should be at a minimum of 1 K above the pool water temperature. Such environmental conditions tend to create high humidity, therefore ventilation should be provided in order to:

— control humidity

— prevent condensation on inner surfaces

— maintain a satisfactory indoor environment including the prevention of down-draughts

— remove airborne pollutants

— dilute disinfectant fumes.

Humidity levels within the pool hall should be maintained between 50–70% RH. For design purposes, airflow rates of 10 litre·s^{-1} per m^2 of total pool hall area and a minimum of 12 litre·s^{-1} per person of outside air should be provided[140]. Overall air change rates of 4–6 ACH are recommended for standard use or 8–10 ACH where there are extensive water features.

Supply and extract rates should be balanced, or preferably set to maintain a marginally lower pressure in the pool hall than outside or in the adjoining accommodation. This will inhibit the migration of moisture and odour. Although bathers out of the water will be susceptible to draughts, air movement at the pool surface must be sufficient to prevent the accumulation of gases released from the chemically treated water.

Warmed air should be provided to maintain changing rooms at 24 °C, and preferably supplied at low level to assist in floor drying if no provision is made for under floor-heating. Permanent extraction from the clothes storage area should be balanced by an air supply at a rate of 6–10 ACH. A separate extract system should be provided for the WCs.

Ventilation systems for swimming pool halls are either 100% fresh air systems or partial recirculation systems. The latter allow the fresh air supply to be adjusted while maintaining the overall supply volumes to the pool hall, hence maintaining air distribution patterns. However, it is essential that damper positions and control regimes are arranged to ensure adequate introduction of fresh air (30% minimum) and expulsion of contaminated air. Internal accumulations of chlorinous by-products are damaging to the building fabric and potentially dangerous to people. Therefore it is necessary to ensure a minimum ventilation rate at all times when the pool is occupied.

Savings can be made by minimising the intake of outside air for the 100% fresh air system using two-speed or variable speed fans. The impact of any savings is increased if a pool cover is used during periods when the pool is not in use. Both 100% fresh air and recirculation based systems are suitable for installing heat recovery and heat pumps or dehumidification systems.

Extract air from pool halls can be corrosive to the internal surfaces of ventilation systems. Adequate protection should be provided for exposed internal surfaces if maintenance and replacement costs are to be kept to a minimum.

2.3.21.8 Ancillary areas

Suitable ventilation systems must also be provided for ancillary areas as shown in Table 2.27. Office areas, rest rooms and circulation spaces may be serviced by natural ventilation. Mechanical extract will be required in kitchen areas to ensure that odours do not reach public spaces. There must be adequate ventilation and segregation for smoking.

2.3.21.9 Operational issues

Ventilation systems can consume nearly half of the energy used in sports centres. Within areas other than swimming pools, more efficient ventilation can be obtained by using the following[141]:

- *variable speed fans*: to cope with varying occupancies or activities, linked to modulating dampers using automatic humidity control
- *ventilation heat recovery and recirculation*: which can reduce running costs for sports centres by 10%.

Maintenance costs represent a high proportion of the total expenditure on a sports building over its lifetime. Routine tasks will be made much easier if appropriate space is allocated for plant rooms, voids and distribution routes. Inspection of many mechanical items will need to take place every three months so there should be easy access to dampers, fans, filters, flexible connections and heat exchangers (plate heat or run-around coils).

2.3.22 Toilets

The Building Regulations[2,37] make specific provision for the ventilation of toilets. In England and Wales, for dwellings, one or more ventilation openings must be provided of area $^1/_{20}$th. of the floor area (some part of which must be at high level, i.e. at least 1.75 m above floor level), or mechanical extract must be provided at a minimum rate of 6 litre·s^{-1}. In non-domestic buildings, sanitary accommodation (which includes washing facilities) again requires either one or more ventilation openings of area $^1/_{20}$th. of the floor area (some part of which must be at high level) or mechanical ventilation at a minimum rate of 6 litre·s^{-1} per WC or 3 air changes per hour.

In Scotland, for dwellings, a ventilator must be provided of area $^1/_{30}$th. of the floor area (some part of which must be at least 1.75 m above floor level), or mechanical extract must be provided at a minimum rate of 3 air changes per hour.

Toilets are very often provided with the absolute minimum ventilation to comply with the regulations, in order to achieve very minor cost savings. The result of such economy can be a unpleasant toilet atmosphere. This unpleasantness is easily avoided at very marginal extra cost by ensuring that the ventilation system exceeds the statutory requirements.

2.3.23 Transportation buildings and facilities

2.3.23.1 General

The exhaust gases produced by combustion engines contain toxic components and smoke. Wherever vehicular access is provided it is necessary to consider how ventilation can be provided that will limit the concentrations of dangerous contaminants to permitted and/or acceptable limits.

2.3.23.2 Tunnels

Road tunnels require ventilation to remove the contaminants produced by vehicle engines in normal use. Ventilation may be provided by natural or mechanical means, or may be traffic induced. Detailed requirements for the ventilation of road tunnels are published by the Highways Agency[142]. Railway tunnels are subject to the requirements of both owners/clients and the Health and Safety Executive's Railways Inspectorate, who should be consulted for detailed design requirements.

2.3.23.3 Car parks

The general requirement is for engineering systems that will remove the hazards of carbon monoxide from vehicle exhaust emissions and prevent the build up of vapours from fuel leaks etc. The increasing use of diesel engined vehicles also requires control of airborne particles.

Above-ground car parks should be provided with natural ventilation openings in the outside walls of at least 5% of the floor area. Openings on opposite sides should be provided to promote ventilation without being adversely effected by wind direction.

Mechanical ventilation is required for car parks that are enclosed or located in basements. The system should be independent of any other systems and provide 6 ACH for normal operation and 10 ACH in a fire condition. Extract points should be placed so as to eliminate pockets of stale air, and be distributed so that 50% of the extract is a high level and 50% at low level, with particular attention at low points and drains. The system should be divided into two parts, each connected to an independent power supply that will continue to operate in the event of mains failure.

Where many vehicle engines are likely to be running simultaneously, e.g. at exit and entrances, consideration should be given increasing the ventilation rates to maintain the acceptable contamination levels based on vehicle emissions. Limiting concentrations of exhaust pollutants are included in the HSE's annual guidance publication EH40: *Occupational Exposure Limits*[43]. If separate from the general car park ventilation system, the ventilation can be controlled using carbon dioxide detectors at appropriate locations.

Manned pay stations may need positive supply air, with the air intake located away from the contaminated roadways.

For further information see ASHRAE Handbook: *HVAC Applications*[143].

2.3.23.4 Bus terminals

Bus terminals vary considerably in physical configuration. Ideally, buses should be able to drive through a loading platform and not have to manoeuvre within the area.

Naturally ventilated terminals with large open ends may expose passengers to inclement weather and strong winds. Therefore, enclosed platforms with appropriate mechanical ventilation should be considered. Alternatively, enclosed passenger waiting areas can be considered for large terminals with heavy bus traffic. The waiting areas can be pressurised and heated, with normal air volumes depending on the layout and number of boarding gates.

The exhaust gases from diesel engines that affect the ventilation design are carbon monoxide, hydrocarbons, oxides of nitrogen and formaldehydes. Exposure limits are given in HSE EH40[43].

The ventilation rate also needs to provide odour control and visibility, which would generally require a 75:1 dilution rate of outside air to bus exhaust gases. The overall rate of fume emission can be determined from considering the bus operation, terminal configuration and traffic movements. The overall ventilation required can be reduced by removing exhaust gases at the point of discharge.

The guidance given above relates to diesel engined vehicles. However, the use of alternative fuels is increasing and these also need to be considered. For buses fuelled by natural gases, the normal emission rate of unburnt fuel is low. However, if the high pressure gas fuel line were to break, then a large quantity of gas would be released causing a potentially explosive atmosphere. Such a situation would require the prompt use of purging ventilation. Initially, the gas, while cold, will collect at ground level and therefore purging needs to be at this level. However, when warmed, methane tends to rise, as will unburnt methane in the exhaust gases. Therefore, potentially stagnant air zones at high level need to be eliminated. For further information see ASHRAE Handbook: *HVAC Applications*[143].

2.3.23.5 Enclosed loading bays

The requirement in ventilating enclosed loading bays is for the dilution of exhaust gases in normal operation and provision for smoke extract under fire conditions.

Consideration should be given to the nature of the loading bay and vehicle movement in order to develop a system that will meet the required standards. Generally, the large entrance door will provide the necessary inlet air and the fume extract can be combined with the smoke extract for general ventilation. As with car parks and enclosed bus terminals, extract should be provided at high and low levels.

2.3.23.6 Garages (vehicle repair)

In view of the dangerous nature of the accessories to the repair and storage of motor vehicles and the risk of pollution from waste gases and products, the heating, ventilation, fire protection and safety of functional structures is regulated.

Ventilation systems should be designed to limit the contamination levels to acceptable limits[42,128]. Where vehicles are stationary at fixed repair stations, direct exhaust for the emissions should be provided by means of a flexible hose and coupling attached to the tailpipe. The use of such systems will reduce the overall ventilation requirement.

Particular care needs to be taken where inspection and repair pits are present as vehicle and fuel fumes, being heavier than air, will tend to flow into these areas. Therefore a separate extract system is required.

Where garages contain spray booths the relevant codes must be complied with.

For further information see ASHRAE Handbook: *HVAC Applications*[143].

2.3.23.7 Railway stations/terminals, underground railway stations

Where the railway tracks are enclosed under a canopy or buildings above, it will be necessary to consider how the fumes produced by the locomotives are to be exhausted/diluted. The design requirements will be similar to those for bus stations, i.e. reduce the level of contaminants and odours to acceptable limits and provide sufficient air circulation to maintain visibility.

For further information see ASHRAE Handbook: *HVAC Applications*[143].

2.3.23.8 Airport terminals

Airports generally consist of one or more terminal buildings, connected by passageways to departure gates. Many terminals have telescoping loading bridges connecting the departure lounges to the aircraft. These eliminate heating and cooling problems associated with open doorways.

The aim of any ventilation system should be to create a positive internal pressure that will prevent the odour and pollutants from entering the buildings.

Terminal buildings have large open circulation areas, check-in facilities, retail outlets, offices and ancillary areas. As occupancy can vary considerably through the day, it is important that the ventilation/air conditioning system is able to respond these changes. However, due to the large volume of the circulation spaces it is possible to use the building volume to absorb the sudden changes and peak flows. Ventilation systems can be designed with recirculation (to provide heat reclaim), controlled by air quality detectors, thereby automatically reacting to passenger flows.

The system design should also incorporate sufficient zone control to accommodate the widely varying occupancy levels in different parts of the building, or even between adjacent departure gates. If available, histograms on passenger movement for departure and arrival are useful in estimating the design occupancy.

Filtering of the outdoor air with activated carbon filters should be considered to reduce the presence of noxious fumes. However, the siting of air intakes away from the aircraft jet exhausts may obviate the need for filtration and will reduce operating costs. However, since it may be difficult to predict if fumes will affect the air intake location, supply systems should incorporate facilities to enable carbon filters to be added at a later stage, if necessary.

2.3.24 Miscellaneous sectors

The following information on other sectors has been included mainly to identify specialist sources of information that are available. Material from the 1986 edition of CIBSE Guide B has been included but not necessarily updated and designers are advised to obtain specialist advice for current guidance.

2.3.24.1 Animal husbandry[144,145]

Farm buildings

Guidance on the housing of animals on farms may be obtained from the Animal Welfare Division of the Department for Environment, Food and Rural Affairs (DEFRA). Reference should also be made to the Welfare of Farm Animals (England) Regulations[146].

Buildings for farm animals fall into two main groups:

- buildings for housing 'hardy stock', such as milking-cows, breeding-pigs and sheep, that do not require any great control of environmental conditions
- buildings such as pig farrowing houses, fattening houses, veal calf houses, laying and broiler poultry houses etc., which require the environmental conditions to be controlled such that the highest possible productivity is obtained at the lowest food and management costs.

Hardy stock require housing only to protect them from extremes of weather, ventilation being provided by low level and ridge ventilators with protection against direct and through draughts. However, care must be taken to ensure adequate ventilation in high density enclosed houses where forced ventilation will be necessary. Humidity is not usually a problem.

Table 2.28 Temperatures and ventilation rates suitable for housed livestock

Animal species	Optimum temperature range / °C	Ventilation rate	
		Winter / (litre·s^{-1} per kg of body weight)	Summer / (litre·s^{-1} per kg of body weight)
Adult cattle	0–20	0.5	0.20–0.38
Calves	10–15	0.10	0.26–0.53
Pigs	5–25	0.10	0.26–0.53
Piglets:			
— at birth	35	0.08	0.08
— after 2 days	28–33	0.06	up to 0.06
Fattening pigs	11–22	0.10	0.26–0.53
Laying poultry	20–25	0.4	1.5–2.6
Broiler chickens	15–25	0.2	0.8–1.3

For animals requiring close control of conditions, mechanical ventilation is essential, provided by supply and/or extract fans depending on the requirement for positive or negative pressures within the houses. Winter recirculation can be used to conserve heat. Safeguards must be provided against fan failure or livestock will be seriously affected during hot weather. Adequate ventilation will also minimise the occurrence of high humidity. Table 2.28 gives optimum air temperatures and ventilation rates.

Animal rooms[147–149]

The specification of the design for animal rooms would be undertaken by the holder of the premises certificate, with the approval of the Home Office local inspector. Designers must ensure that all necessary procedures are followed. The environmental conditions and degree of control required for animal rooms depend on the species and the intended use of the facilities. Tables 2.28 and 2.29 show the conditions required for various animals and for different applications.

For precise experimental work, close control of temperature (±1 K) and relative humidity (±10%) may be required at different conditions within the overall operational stage. Uniformity of the environment throughout the space is also important and in some cases the direction of air movement needs to be controlled to minimise, for example, the pollution in the spaces through which the laboratory operatives move.

Requirements may also include standby equipment and/or safety features that are automatically initiated in the event of a failure of the main system.

2.3.24.2 Call centres

Concern has been expressed regarding employee motivation and stress in telephone call centres. Little guidance has been produced on the ventilation aspects of call centre design, precedence being given to acoustic and lighting issues. This is partly due to the disparate nature of call centres.

The ideal call centre is characterised by space 15–18 m in depth on a single level, operator teams of up to 12–15 people, large floor-to-ceiling heights, good ventilation, and lighting, and raised floors[150]. However, in reality, call

Table 2.29 Animal room environmental design conditions

Animal	Surface area / m^2	Average metabolic rate at 21 °C* / W	Number of animals per 10 m^2 of floor area	Typical animal room gain / W·m^{-2}	Recommended temperature range / °C	Relative humidity / %
Mice	0.01	0.5	2000	100	21–23	40–70
Rats (at 60 days)	0.031	1.5	485	73	21–23	40–60
Guinea pigs (at 60 days)	0.07	3.0	400	120	17–20	40–70
Chicken:						
— at 4 weeks	0.04	2.4	230	55	21–23	40–60
— at 24 weeks	0.21	12.0	100	120	16–19	40–60
Rabbits (adult)	0.20	11.0	32	35	16–19	40–60
Cats	0.20	8.0	16	13	18–21	40–60
Dogs:						
— male	0.65	26.0	5	13	12–18	40–70
— female	0.58	22.0	5	11	12–18	40–70

*Based on resting metabolism *Notes*: (1) Assume 35–40% as latent gain. (2) Figures should be used as a guide only and will vary depending on conditions. (3) Animal numbers per m^2 based on figures for an average experimental holding room.

centres are housed in a large variety of building types from converted warehouses to highly specified office buildings.

Space occupancy densities also vary. There may be as little as 6–7 m^2 per person in a centre dealing with simple enquiries or as much as 10–14 m^2 per person in newer, full service centres or where confidentiality is important[151]. The latter figure allows for support areas such as lounges, catering, training facilities and team meeting areas. The subsequent amount and concentration of heat gains will therefore vary and may result in the selection of, for example, VAV, chilled ceilings/beams or fan coils.

The ventilation system designer should be aware of:

- the intended staffing levels and how these might change in the future (e.g. additional staff) as this will affect cooling loads and the potential requirement for upgrading the system
- the pattern of changing staff levels over the day, week or seasonal basis (e.g. as a consequence of shift patterns); this could affect system zoning and the ability to use night cooling as a pre-cooling strategy, or as a free cooling strategy
- the degree to which staff operate IT equipment, e.g. single or multiple screen systems
- the anticipated importance of 'churn' (e.g. will temporary areas be screened-off for periods within open plan areas, thereby interrupting airflow and causing pockets of stale air?)
- the maintenance constraints imposed by the system selection and shift arrangements (will it be necessary to isolate as much plant as possible away from the working space to facilitate ongoing maintenance?)
- the potential need to separated off areas within the space (either by full height partitions or screens) to protect the open plan workstations from noise and distraction and to separate support functions and office equipment
- the support features that will be provided and whether or not they will require separate servicing (e.g. is there a need to isolate hot snack areas to prevent odours from drifting?)
- the interaction between the ventilation system and individual staff; it is important to ensure a good quality environment across the entire space as staff will be unable to change the position of their work stations or alter the ventilation
- the possibility that the ventilation system will add to background noise levels and thereby affect the ability of staff to deal with incoming calls.

2.3.24.3 Court rooms

The Lord Chancellor's Department (LCD) should be consulted for guidance on environmental policy and court room design[152,153].

The LCD's policy is to maximise the use of natural ventilation principles to maintain satisfactory environmental conditions as part of their commitment to provide environmentally friendly buildings.

Mechanical ventilation systems for court rooms need to be designed to meet the sound control requirements as set out in section 5 of this guide.

2.3.24.4 Darkrooms (photographic)

Small darkrooms for occasional use or for purely developing processes may often be ventilated naturally with a suitable light trap, although consideration should be given to providing mechanical extract using an air change rate of 6 to 8 air changes per hour. For general purpose darkrooms, however, the air change rate should be ascertained from consideration of the heat gain from the enlarger, lights etc. plus the occupants, on the basis of a temperature rise of 5–6 K. In industrial and commercial darkrooms that have machine processing, the machines will very often have their own extract ducting, the air supply being drawn from the room itself. It will usually be necessary to provide a warmed and filtered mechanical inlet in such cases. In special cases, involving extensive washing processes, the humidity gain may be significant and require consideration.

2.3.24.5 Dealing rooms

Dealing rooms are characterised by much higher heat gains from IT equipment than those for general office areas. Small power requirements are typically in the order of 500 W per trading desk, but can vary between 200 and 1000 W[154]. Occupation densities can be as high as one trading desk per 7 m^2.

Loads are a function of the IT equipment and are subject to technological developments. Developments may have spatial as well as power implications. These may affect load intensity. For example, flat panel displays (FPD) have lower cooling requirements than cathode ray tubes (SRT) displays, but occupy less space thereby permitting a greater density of occupation[155].

The selection of suitable air conditioning is primarily determined by the high cooling load. The need to minimise disruption, reliability and maintenance requirements are is a key consideration. Systems normally incorporate a high degree of redundancy. Risks associated with pipework and condensate leakage should be minimised.

Ceiling mounted system options include fan coils and variable air volume (VAV) systems. However, supplying cooling from above to deal with the heat from the equipment will create a large amount of air movement, thereby increasing the risk of draughts. An alternative approach is to supply cool air directly to desktop computers through the floor void to remove the heat directly, reducing air movement in the occupied space and the risk of draughts. This approach may be used in conjunction with the fan coil units, VAV system or chilled beams/ceilings that deal with the balance of the load.

Mechanical ventilation systems for dealing rooms need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building.