

Code of practice for

Mechanical ventilation and air conditioning in buildings —

(formerly CP 352)

UDC 697.9

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The Refrigeration, Heating and Air Conditioning Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

- Association of Consulting Engineers
- Association of Manufacturers of Domestic Electrical Appliances
- Boiler and Radiator Manufacturers' Association Limited
- British Combustion Equipment Manufacturers' Association
- British Gas Corporation*
- British Refrigeration and Air Conditioning Association*
- Building Services Research and Information Association
- Chartered Institution of Building Services*
- Department of the Environment (PSA)*
- Department of Health and Social Security*
- Engineering Equipment Users' Association
- Electricity Supply Industry in England and Wales*
- Heating and Ventilating Contractors' Association*
- Hevac Association*
- Institute of Fuel
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- Lloyd's Register of Shipping
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- Ministry of Defence*
- National Coal Board
- Society of British Gas Industries
- Water-tube Boilermakers' Association

The organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Greater London Council

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Contents

	Page
Cooperating organizations	Inside front cover
Foreword	ii
Section 1. General	1
Section 2. Fundamental requirements	1
Section 3. Design considerations	18
Section 4. Types and selection of equipment	36
Section 5. Installation	64
Section 6. Inspection, commissioning and testing	79
Section 7. Operation and maintenance	82
Section 8. Overseas projects	85
Appendix A Bibliography	88
Index	89
Figure 1 — Simplified block diagram of centralized control system	54
Table 1 — Recommended minimum fresh air supply rates for air-conditioning spaces	3
Table 2 — Recommended design values for dry resultant temperature, t_c (heating season)	6
Table 3 — Comfort design conditions for the United Kingdom (summer season)	7
Table 4 — Levels of relative humidity, for an internal temperature of 21 °C, at which condensation will occur at various outside temperatures	7
Table 5 — Recommended broadband continuous noise ratings	8
Table 6 — Methods of speed control	30
Table 7 — Basic components of a control system	51
Table 8 — Motor speeds	63
Publications referred to	96

Foreword

The original code of practice CP 352:1958 was prepared by a committee convened by the Institution of Mechanical Engineers and the Institution of Heating and Ventilating Engineers (now the Chartered Institution of Building Services) on behalf of the former Council for Codes of Practice for Buildings (Construction and Engineering Services).

The present revision has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee. CP 352 is now withdrawn.

Since the original code was published, the industry has undergone rapid development and services within buildings have become much more complex until today they often account for over 50 % of the initial capital cost. The services engineer is now recognized as an influential member of the building team.

In this context several aspects were clearly apparent; first the original code has become so outdated as to warrant completely rewriting, secondly much data included in the original code has been revised, expanded and extended in scope by other bodies more immediately involved and finally there had been identified a need for an overall guide to the whole complex process of ventilating and air conditioning a modern building written from the standpoint of the services engineer but with allied professionals in mind.

It is hoped that this code will be used by all those concerned with ensuring that a client obtains what he expects to receive, and who wish to understand the interrelation of the multitude of actions necessary to achieve that end. The decision that the code should be broadly based inevitably means that some users will not be engineers. It has been necessary therefore to include brief descriptions of certain systems and items of equipment which, it is hoped, will make the code intelligible to those without the specialist training of the services engineer.

A bibliography, together with addresses of the issuing authorities, is given in Appendix A

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 96, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This code deals with the work involved in design, installation, commissioning, operation and maintenance of mechanical ventilation and air-conditioning systems. The recommendations made in this code recognize the need to optimize the use of energy, reduce hazards and minimize effects detrimental to the environment. The increasing involvement of British engineers in projects overseas is noted and some guidance given in that context. In addition to this general section, the code is divided into the following seven sections:

- Section 2. Fundamental requirements
- Section 3. Design considerations
- Section 4. Types and selection of equipment
- Section 5. Installation
- Section 6. Inspection, commissioning and testing
- Section 7. Operation and maintenance
- Section 8. Overseas projects.

1.2 References

1.2.1 British Standards. The titles of the British Standards referred to in this code are listed on the inside back cover, together with others that are applicable.

1.2.2 Other publications. The policy adopted when writing this code has been to avoid repetition of material for which other bodies are the accepted authority, except in so far as limited extraction assists the understanding of this code. Consequently the code provides broad guidance only on certain topics. References in this category are:

- a) for detailed design procedures:
 - 1) publications of the Chartered Institution of Building Services, particularly:
 - The CIBS Guide
 - CIBS Building Energy Code
 - Technical Memoranda relating to fire and smoke control
 - Practice Notes relating to provision of combustion and ventilation air for boiler installations;
 - 2) the "Ductwork Specifications" published by the Heating and Ventilating Contractors' Association (HVCA);
 - 3) ASHRAE Handbooks published by the American Society of Heating, Refrigerating and Air Conditioning Engineers.
- b) for detailed commissioning arrangements:
 - 1) CIBS Commissioning Codes;

2) BSRIA Application Guides published by the Building Services Research and Information Association.

1.2.3 Acts of Parliament, Regulations, etc. Reference is made in the text to a number of Acts of Parliament and to various Regulations laid under them. Such lists are necessarily incomplete, and in any particular circumstance, the users of this code should acquaint themselves with the relevant regulations in force at the time.

1.3 Definitions

The definitions of most terms used in this code are to be found in BS 5643. Other terms not in BS 5643 are defined where they occur in the text.

Section 2. Fundamental requirements

2.1 General

The object of providing ventilation and air-conditioning facilities in buildings is to provide conditions under which people can live in comfort and work safely and efficiently.

The purpose of this section of the code is to relate the various controllable factors to the comfort and well-being of the people using the building, so that the requirements of the system may be specified to the designers and the contractors.

Modern business and commercial premises often contain office and data processing equipment that in certain cases requires special standards of temperature and humidity control and of air filtration. Such requirements should be established when the building layout is planned, so that necessary provision can be made for local air-conditioning.

While this code does not refer in detail to factory production or assembly processes, or to hospitals, or to other such situations with special requirements, some general recommendations are given in 2.4.3.

2.2 Necessity for mechanical ventilation and air-conditioning

2.2.1 Ventilation. Ventilation is the process of changing air in an enclosed space. A proportion of the air in the space should be continuously withdrawn and replaced by fresh air drawn in from external sources to maintain the required level of air purity. Ventilation is necessary to control:

- a) *oxygen content*, preventing depletion of the oxygen content of the air;
- b) *carbon dioxide and moisture*, preventing undue accumulation of carbon dioxide and moisture;

- c) *contaminants*, preventing an undue concentration of body odours and other contaminants such as tobacco smoke;
- d) *bacteria*, preventing an undue concentration of particles carrying bacteria;
- e) *heat*, in some cases to remove body heat and heat liberated by the operation of electrical and mechanical equipment (e.g. artificial lighting and office machinery).

2.2.2 Air conditioning. Air conditioning is the control within predetermined limits of the temperature and humidity inside the building, accommodating the internal heat gains in conjunction with the external ambient conditions. The air, as well as being filtered, is heated or cooled as necessary and moisture is added or extracted to give a controlled humidity.

2.3 Comfort factors

2.3.1 General. A wide range of external environmental conditions can be accepted by varying clothing or physical activity. It is desirable that the internal environment be controlled to minimize any variation. Such comfort conditions, the lack of which can affect the welfare of people, are provided by controlling the temperature, humidity and air movement. These factors interact with each other and with similar external factors and when in balance over a range of combinations can achieve acceptable conditions. Despite the need to produce a comfortable internal environment, care should be taken to avoid too great a difference with the external summer conditions thereby avoiding the effects of thermal shock on people and minimizing the energy use of the system selected.

It is considered impractical to cover all aspects of comfort conditions in this code of practice and therefore it is recommended that reference be made to the CIBS Guide.

The factors that affect comfort and that can be controlled by an air-conditioning installation are:

- a) ventilation and air movement (2.3.2);
- b) air purity and filtration (2.3.3);
- c) resultant temperature (2.3.4);
- d) humidity (2.3.5);
- e) noise and vibration (2.3.6).

2.3.2 Ventilation and air movement. There are a number of factors that should be considered in deciding the ventilation rates of a building.

NOTE In addition to the mandatory requirements such as Building Regulations etc. (see 2.5), further information on this subject can be obtained from the CIBS Guide and CP 3:Chapter I(C).

2.3.2.1 Fresh air supply. The fresh air supply is required to maintain an acceptably non-odorous atmosphere (by diluting body odours and tobacco smoke) and to dilute the carbon dioxide exhaled. This quantity may be quoted per person and is related to the occupational density and activity within the space. Table 1 gives minimum fresh air supply rates for mechanically ventilated or air-conditioned spaces.

The quantity and distribution of introduced fresh air should take into account the natural infiltration of the building.

The proportion of fresh air introduced into a building may be varied to achieve economical operation. When the fresh air can provide a useful cooling effect the quantity is controlled to balance the cooling demand. However, when the air is too cool, the quantity is reduced to a minimum to limit the heating load. Similarly, when the air is too warm or humid, the quantity is reduced to a minimum to reduce the cooling load.

2.3.2.2 Transfer of heat/moisture. Air circulation is required to transfer the heat and humidity generated within the building. In simple systems the heat generated by the occupants, solar heat and heat from electrical and mechanical equipment may be removed by the introduction and extraction of large quantities of fresh air. In more elaborate systems air may be recirculated through conditioning equipment to maintain the desired temperature and humidity. The air circulation rates are decided in relation to the thermal or moisture loads and the practical cooling or heating range of the air.

2.3.2.3 Air movement

- a) *In rooms.* Air movement is desirable, as it contributes a feeling of freshness, although excessive movement should be avoided as this leads to complaints of draughts. The speed of an air current becomes more noticeable as the air temperature falls, owing to its increased cooling effect. The design of the air-distributing system therefore has a controlling effect on the quantity and temperature of the air that can be introduced into a space. The quantity of fresh air should not be increased solely to create air movement; this should be effected by air recirculation within the space or by inducing air movement with the ventilation air stream.

Table 1 — Recommended minimum fresh air supply rates for air-conditioning spaces^a

Reproduced with permission from the CIBS Guide.

Typical type of space	Smoking	Outdoor air supply ^b		
		Recommended	Minimum (the greater of the two should be taken)	
			Per person	Per m ² floor area
Factories ^{de}	None	dm ³ /s ^c	dm ³ /s ^c	dm ³ /s ^c
Offices (open plan)	Some			0.8
Shops, department stores and supermarkets	Some	8	5	1.3
Theatres ^d	Some			3.0
Dance halls ^d	Some			—
Hotel bedrooms ^e	Heavy			1.7
Laboratories ^e	Some	12	8	—
Offices (private)	Heavy			1.3
Residences (average)	Heavy			—
Restaurants (cafeteria) ^{ef}	Some			—
Cocktail bars	Heavy			—
Conference rooms (average)	Some	18	12	—
Residences (luxury)	Heavy			—
Restaurants (dining rooms)	Heavy			—
Board rooms, executive offices and conference rooms	Very heavy	25	18	6.0
Corridors	A per capita basis is not appropriate to these spaces			1.3
Kitchens (domestic) ^e				10.0
Kitchens (restaurant) ^e				20.0
Toilets ^d				10.0

^a For hospital buildings (wards, operating theatres, etc.), see Department of Health and Social Security Building Notes.^b The outdoor air supply rates given take account of the likely density of occupation and the type and amount of smoking.^c 1 dm³/s = 1 litre/s.^d See statutory requirements and local bye-laws.^e Rate of extract may be over-riding factor.^f Where queuing occurs in the space, the seating capacity may not be the appropriate total occupancy.

b) *In buildings.* Air flows within a building should be controlled to minimize transfer of fumes and smells, e.g. from kitchens to restaurants and the like. This is achieved by creating air pressure gradients within the building, by varying the balance between the fans introducing fresh air and those extracting the stale air. For example, the pressure should be reduced in a kitchen below that of the adjacent restaurant.

Care should be taken, however, to avoid excessive pressure differences that can cause difficulty in opening doors or cause them to slam. In other cases, such as computer rooms, the area may be pressurized to minimize the introduction of dust from adjacent areas.

2.3.2.4 Fire and smoke control. Air circulation systems may be designed to extract smoke in the event of a fire, to assist in the fire fighting operations and to introduce fresh air to pressurize escape routes.

2.3.3 Air purity and filtration

2.3.3.1 General. A ventilation or air-conditioning system installed in a building should clean, freshen or condition the air within this space. This can be achieved by providing the required amount of fresh air either to remove totally or to dilute odours, fumes, etc. (e.g. from smoking). Local extract systems may be necessary to remove polluted air from kitchens, toilets, etc. Special air filters may be required to remove contaminants or smells when air is recirculated.

Positions of air inlets and extracts to the system are most important and care should be taken in their location. Consideration should be given to relatively nearby buildings and any contaminated discharges from those buildings. Inlets should not be positioned near to any flue outlets, dry cleaning or washing machine extraction outlets, kitchens, WC's, etc. When possible, air inlets should be at high level so as to induce air from as clean an area as possible. If low-level intakes are used, care should be taken to see that they are positioned well away from roadways and car parks.

2.3.3.2 Removal of particulate matter from air.

Efficient air filtration prevents fouling of the system and is of special importance in urban areas, where damage is likely to be caused to decorations and fittings by discoloration owing to airborne dust particles. In order to obtain maximum filtration efficiency with the minimum capital and maintenance expenditure, the utmost care should be given to the location of the air intake in relation to the prevailing wind, the position of chimneys and the relative atmospheric dust concentration in the environs of the building; the recommendations of 2.3.3.1 for siting of air inlets should not be overlooked. Air filtration equipment should be regularly serviced (see 7.4.2).

Airborne dust and dirt can be generated within the building, from the personnel and their movements as well as by machines, such as those used for card sorting.

The degree of filtration necessary will depend on the use of the building or the conditioned space. Certain specialized equipment, normally associated with computers, will require higher than normal air filter efficiencies for satisfactory operation. It is important to ascertain the necessary standard of air cleanliness required for equipment of this type.

The choice of filtration systems will depend on the degree of contamination of the air and on the cleanliness required. A combination of filter types may well give the best service and the minimum operating costs.

Filter efficiency is conveniently referred to as its performance on standard test dusts. BS 2831 includes three different dust grades of which no. 1 (particle size range 0.03 μm to 2 μm) and no. 2 (particle size range 2 μm to 14 μm) are normally used.

The normal standard for intake filters in ventilating and air-conditioning applications in the United Kingdom is an efficiency of 95 % against BS 2831 test dust no. 2 although there may be a requirement for a higher efficiency to give increased protection against atmospheric staining.

Special applications, such as computer suites, pharmaceutical or food processing, and air systems having induction units, require a higher standard that is achieved by two stage filtration. The exact requirements will depend on the equipment or process involved.

2.3.3.3 Removal of fumes and smells from air.

Fumes and smells can be removed from air by physical or chemical processes. These may be essential when the ambient air is heavily polluted, although it may be possible to limit operating costs by minimizing the thermal loads caused by the introduction of large quantities of fresh air. The decision to use odour-removing equipment will normally be made on economic grounds, but the arguments in its favour will be increased by the currently rising cost of fuel. Once this equipment is installed, it should be regularly serviced to ensure satisfactory performance (see 7.4.2). Failure to do this can result in unacceptable conditions within the building.

2.3.4 Temperature

2.3.4.1 General considerations. Certain minimum temperatures are required by legislation and by local regulations. Maximum permitted heating temperatures may be stipulated by legislation relating to energy conservation.

From the comfort aspect, it is important to take into account the effect of radiant temperature in fixing the desired air temperatures to maintain comfortable conditions. When heating is provided from radiating floors, ceilings or walls, air temperatures may be reduced. Radiation losses to large windows or cold external walls may require an upward adjustment in air temperature.

When large windows are used, it may be necessary to provide shading to protect the occupants from solar radiation and to reduce the cooling load on the system. It is not practical to fully compensate for solar heating, owing to its intermittent nature, simply by lowering air temperature.

A person's heat loss, and hence his feeling of warmth, depends not only on the air temperature but on his radiant heat gain, the air movement and the humidity of the air. Many attempts have been made to devise a single index that combines the effect of two or more of these separate variables. In practice the difference between these indices is small, provided the various parameters do not vary beyond certain limits.

2.3.4.2 Design temperatures. It should be noted that, although comfort conditions and heat requirements are established in terms of resultant temperature, the design air temperature for air conditioning should be specified in terms of dry bulb temperature and relative humidity or wet bulb temperature.

Table 2 and Table 3 show the recommended design values for dry resultant temperature and comfort design conditions, respectively, for the United Kingdom. The relationship between air dry bulb temperature and dry resultant temperature is established in the CIBS guide.

2.3.5 Humidity

2.3.5.1 Comfort considerations. The controlled temperature levels should also be considered in relation to the humidity of the air. A high humidity reduces evaporative cooling from the body and hence creates the sensation of a higher temperature. Beyond certain limits, however, humidity produces disagreeable sensations.

For normal comfort conditions, relative humidity (r.h.) values between 40 % and 70 % are acceptable.

2.3.5.2 Condensation. Condensation can occur on windows when the surface temperature falls below the room air dew point temperature. This tendency is increased with low ambient temperatures, high wind velocities and high internal humidities.

For the United Kingdom with a room temperature of 21 °C and normal wind exposures, Table 4 details the room r.h. values at which condensation will occur at various outside temperatures.

2.3.5.3 Electrostatic effects. Low humidities can increase electrostatic effects, in particular on modern synthetic materials, for example on nylon carpets, which can rapidly accumulate high charges. These effects can be minimized by maintaining humidities greater than 40 %, but preferably by antistatic sprays and surface treatments.

2.3.5.4 Dimensional changes. Variations in humidity can cause problems with natural materials and others that may be hygroscopic and whose moisture contents change with the relative humidity of the air. This can lead to warping of woodwork and cracking of paintings; thus control of atmospheric conditions is particularly important in museums and art galleries. The important feature in these cases is the avoidance of rapid changes in temperature and humidity, the actual values being of lesser importance providing they are within the ranges 20 °C to 25 °C and 40 % r.h. to 55 % r.h.

2.3.5.5 Computer rooms. The temperature and humidity in computer rooms needs to be controlled within reasonably close limits, although this depends on the equipment involved. Humidity control within ± 5 % in the range 40 % r.h. to 60 % r.h. is normal.

2.3.6 Noise and vibration

2.3.6.1 General. Noise is unwanted sound. All ventilating and air-conditioning systems will produce noise, and this may cause annoyance or disturbance in:

- a) the spaces being treated;

- b) other rooms in the building;

- c) the environment external to the building.

In the case of the external environment particular care should be taken to avoid a nuisance in the “silent” hours, and local authorities have statutory powers to ensure that noise from plant is limited. BS 4142 explains a noise measurement procedure, the determination of corrected noise level and a method of rating the noise in these instances.

It is important that expert advice be sought in dealing with noise and vibration problems, as for obvious reasons the most economical solutions should be used without impairing the performance.

2.3.6.2 Types of noise in buildings

2.3.6.2.1 Externally created noise. Exclusion of externally created noise is mainly dealt with by choice of building and window construction. The air-conditioning engineer should, however, ensure that noise does not enter via air inlets or exhausts: it may be reduced by suitable attenuators.

2.3.6.2.2 Generated noise. Noise produced by the air-conditioning and ventilation plant installed within the building can escape via ventilation grilles or door openings and can cause nuisance to neighbours. Equipment mounted outside the building may well need to be selected or installed with the noise problem in mind.

Another type of generated noise is created by the air-circulating system itself and its associated equipment. Fans are an obvious source, but noise can be produced by turbulence, which may cause vibration of the ducts themselves, and by air diffusers. This problem can be avoided by careful selection of equipment or by arranging that the noise be absorbed.

2.3.6.2.3 Transmitted noise. Noise transmitted through the building structure is particularly acute in modern frame and reinforced concrete buildings. Such noise can be controlled by isolating the machines from the structures, and from pipework connected to the building, by suitable mountings and pipe couplings.

Another problem is the transmission of sound from one room to another via air ducting, ventilated ceilings or other continuous air space. Such sound includes the noise from machines and equipment and also of conversation, transmission of which can be embarrassing as well as annoying. Again, this problem can be met by careful design and the inclusion of sound-absorbing linings to ducts, attenuators, etc.

Table 2 — Recommended design values for dry resultant temperature, t_c (heating seasons)

Reproduced with permission from the CIBS Guide.

Type of building	t_c	Type of building	t_c
	°C		°C
Art galleries and museums	20	Hotels:	
Assembly halls, lecture halls	18	Bedrooms (standard)	22
Banking halls	20	Bedrooms (luxury)	24
Bars	18	Public rooms	21
Canteens and dining rooms	20	Corridors	18
Churches and chapels:	18	Foyers	18
Vestries	20	Laboratories	20
Dining and banqueting halls	21	Law courts	20
Exhibition halls	18	Libraries:	20
Factories:		Stack room	18
Sedentary work	19	Store rooms	15
Light work	16	Offices:	
Heavy work	13	General	20
Fire stations; ambulance stations:		Private	20
Appliance rooms	15	Stores	15
Watch rooms	20	Police stations:	
Recreation rooms	18	Cells	18
Flats, residences and hostels:		Restaurants and tea shops	18
Living rooms	21	Schools and colleges:	
Bedrooms	18	Classrooms	18
Bed-sitting rooms	21	Lecture rooms	18
Bathrooms	22	Studios (see also DES Bulletins)	18
Lavatories and cloakrooms	18	Shops and showrooms:	
Service rooms	16	Small	18
Staircase and corridors	16	Large	18
Entrance halls and foyers	16	Department store	18
Public rooms	21	Fitting rooms	21
Gymnasias	16	Store rooms	15
Hospitals:		Sports pavilions:	
Corridors	16	Dressing rooms	21
Offices	20	Swimming baths:	
Operating theatre suite	18 – 21	Changing rooms	22
		Bath hall	26
Stores	15	(See also MOHLG Design Bulletin 4)	
Wards and patient areas	18	Warehouses:	
Waiting rooms	18	Working and packing spaces	16
(See also DHSS Building Notes)		Storage space	13

Table 3 — Comfort design conditions for the United Kingdom (summer season)

Occupancy	Design criteria	
	Dry resultant temperature	Relative humidity
	°C	%
Continuous	20 to 22	50
Transient	23	50
NOTE The above values may be adjusted upwards in accordance with the recommendations of the CIBS Building Energy Code.		

Table 4 — Levels of relative humidity, for an internal temperature of 21 °C, at which condensation will occur at various outside temperatures

Outside temperature °C	Relative humidity	
	Single glazing	Double glazing
	%	%
– 20	14	32
– 10	24	44
0	40	59
+ 10	61	74

2.3.6.2.4 Intermittent noise. Such noise arises from the stopping and starting of equipment, and the opening and closing of valves and dampers. This may or may not cause problems in the air-conditioned spaces, but it is often objectionable to plant operators and maintenance engineers.

2.3.6.3 Sources of noise

2.3.6.3.1 Central plant. Noise is produced by boilers, pumps, fans, compressors, cooling towers, etc.

2.3.6.3.2 Distribution systems. Noise is produced by:

- a) the effect of air velocity in ducts particularly through dampers or restrictions or air leakage;
- b) drumming from duct walls;
- c) turbulence;
- d) excessive fluid velocity or throttling in pipes and at valves;
- e) pick-up of noise or vibration from plant rooms, etc., and transmission along ductwork or pipework, cross-talk or noise transfer from one occupied space to another, etc.

2.3.6.3.3 Sources in occupied rooms. The noise arises from local fans, induction units, high velocity units, self-contained unit air conditioners, air flow through grilles and diffusers.

2.3.6.3.4 Architectural treatment. Open plan layouts, use of false ceilings, etc., can often cause noise problems.

2.3.6.4 Noise ratings. It is established that continuous exposure to noise rating values above 85 can cause permanent damage to hearing. This problem can be dealt with in two ways.

2.3.6.4.1 Selection of treatment. Noise levels can be reduced in the room by appropriate selection or acoustic shrouding of machines. In some cases, treatment of plant room walls and ceilings can alleviate the problem, but this is not usually economical or even adequate.

2.3.6.4.2 Duration of exposure. The problem can be dealt with by ensuring that no one needs to be exposed continuously to excessive noise levels, and by providing hearing protection to be worn for maintenance or service duties.

2.3.6.5 Recommended levels of noise. The levels of environmental noise are most conveniently related to noise rating curves. These curves are attempts to relate the background noise level for annoyance and speech intelligibility for a given environment.

Table 5 gives recommended broadband continuous noise ratings for different situations, in the unoccupied condition.

2.4 Application factors

2.4.1 General. This subclause gives general guidance, for various applications, on the factors that usually influence the selection of the type, design and layout of the air-conditioning or ventilating system to be used. See also 2.6 and the CIBS Building Energy Code.

2.4.2 Commercial applications. The primary objective of the applications described under this heading is provision of comfort conditions for occupants.

2.4.2.1 Offices. Office buildings may include both external and internal zones.

The external zone may be considered as extending from approximately 4 m to 6 m inwards from the external wall, and is generally subjected to wide load variations owing to daily and annual changes in outside temperature and solar radiation. Ideally, the system(s) selected to serve an external zone should be able to provide winter heating and summer cooling. During intermediate seasons the external zone of one side of the building may require cooling at the same time as the external zone on another side of the building requires heating. The main factors affecting cooling load are usually window area and choice of shading devices; the other important factors are the internal gains owing to people, lights and office equipment. Choice of system may be affected by requirements to counteract draughts and cold radiation associated with single glazing during winter.

Internal zone loads are due almost entirely to people, lights and office equipment, which represent a fairly uniform cooling load throughout the year.

Other important considerations in office block applications may include requirements for individual control, partitioning flexibility serving multiple tenants, and operating selected areas outside of normal office hours. Areas such as conference rooms, board rooms, canteens, etc., will often require independent systems.

Experience indicates that for external building zones with large glass areas, e.g. greater than 60 % of the external facade, the air-water type of system, such as induction or fan-coil, is generally more economical than all-air systems and has lower space requirements. For external zones with small glass areas, an all-air system, such as variable volume, may be the best selection. For buildings with average glass areas, other factors may determine the choice of system.

For internal zones, a separate all-air system with volume control may be the best choice. Systems employing reheat or air mixing, while technically satisfactory, are generally poor as regards energy conservation.

Unitary systems may be suitable for both external and internal zones, particularly in the smaller and medium sized building, but are generally only cost-effective when the module size (area served by one unit) is relatively large.

2.4.2.2 Hotel guest rooms. In ideal circumstances, each guest room in a hotel or motel should have an air-conditioning system that enables the occupant to select heating or cooling as required to maintain the room at the desired temperature. The range of temperature adjustment should be reasonable but, from the energy conservation viewpoint, should not permit wasteful overheating or overcooling.

Guest room systems are required to be available for operation 24 h a day, 7 days a week. The room may be unoccupied for most of the day and provision for operating at reduced capacity, or switching off, is essential. Low operating noise level, reliability and ease of maintenance are essential. UK systems are frequently of the unitary or air-water type, and may be located either below window or at high level above the bathroom/lobby area. Fresh air introduced through the system is generally balanced with the bathroom extract ventilation to promote air circulation into the bathroom. In tropical climates, where the humidity is high, an all-air system with individual room reheat (and/or recool) may be necessary to avoid condensation problems.

Table 5 — Recommended broadband continuous noise ratings

Reproduced with permission from the CIBS Guide.

Situation	NR value
Concert halls, opera halls, studios for sound reproduction, live theatres (> 500 seats)	20
Bedrooms in private homes, live theatres (< 500 seats), cathedrals and large churches, television studios, large conference and lecture rooms (> 50 people)	25
Living rooms in private homes, board rooms, top management offices, conference and lecture rooms (20 to 50 people), multipurpose halls, churches (medium and small), libraries, bedrooms in hotels etc., banqueting rooms, operating theatres, cinemas, hospital private rooms, large courtrooms	30
Public rooms in hotels etc., ballrooms, hospital open wards, middle management and small offices, small conference and lecture rooms (< 20 people), school classrooms, small courtrooms, museums, libraries, banking halls, small restaurants, cocktail bars, quality shops	35
Toilets and washrooms, drawing offices, reception areas (offices), halls, corridors, lobbies in hotels etc., laboratories, recreation rooms, post offices, large restaurants, bars and night clubs, department stores, shops, gymnasia	40
Kitchens in hotels, hospitals, etc., laundry rooms, computer rooms, accounting machine rooms, cafeteria, canteens, supermarkets, swimming pools, covered garages in hotels, offices, etc., bowling alleys, landscaped offices	45
NR 50 and above	
NR 50 will generally be regarded as very noisy by sedentary workers, but most of the classifications listed under NR 45 could just accept NR 50. Noise levels above NR 50 will be justified in certain manufacturing areas; such cases should be judged on their own merits.	
NOTE 1 The ratings listed above will give general guidance for total services noise, but limited adjustment of certain of these criteria may be appropriate in some applications.	
NOTE 2 The intrusion of high external noise levels may, if continuous during occupation, permit relaxation of the standards, but services noise should be not less than 5 dB below the minimum intruding noise in any octave band to avoid adding a significant new noise source to the area.	
NOTE 3 Where more than one noise source is present, it is the aggregate noise that should meet the criterion.	
NOTE 4 NR dBA value – 6	
NOTE 5 Where impulsive and/or intermittent noise, or easily perceptible pure tones, are present, the design NR values in the table should be reduced by 5.	

All fan-coils should be arranged so that if the fan is shut off the cooling coil control valve will close, otherwise excessive condensation and damage may result.

For UK applications, or in similar climates, consideration should be given to provision of bathroom heating.

2.4.2.3 Restaurants, cafeterias, bars and nightclubs. Such premises have several factors in common; highly variable loads, with high latent gains (low sensible heat factor) owing to occupants and meals, and high odour concentrations (body, food and tobacco smoke odours) requiring adequate control of fresh air extract volumes and direction of air movement. Particular attention should be paid to infiltration loads, operating noise levels, control of air movement (avoidance of draughts), and make-up air requirements for associated kitchens (to ensure an uncontaminated supply).

This type of application is generally best served by the all-air type of system, preferably with some reheat or return air bypass control to limit relative humidity. Either self-contained packaged units, or split-systems, or air handling units served from a control chilled water system may be used. Sufficient control flexibility to handle adequately the complete range of anticipated loads is essential.

2.4.2.4 Department stores/shops. For small shops and stores unitary air-conditioning systems (3.1.2.3) offer many advantages, including low initial cost, minimum space requirements and ease of installation.

For large department stores a very careful analysis of the location and requirements of individual departments is essential as these may vary widely, e.g. for lighting departments, for food halls, for restaurants, etc. Some system flexibility to accommodate future changes may be required.

Generally, internal loads (lighting and people) predominate. Important considerations include initial and operating costs, system space requirements, form of maintenance to be provided, and who will operate the system (very necessary in determining the type of control system to be installed).

The all-air type of system, with variable volume distribution from local air handling units (minimizing duct runs), may be the most economical. Facilities to take all outside air for “free-cooling” under favourable conditions should be provided. In this case, heating and cooling media would be piped from a central service.

Many newer department stores are “self-heating” down to an outside temperature of about 5 °C owing to their high internal loads, and heat recovery air conditioning (3.1.3.2) or various conservation measures (4.12) may be economically attractive.

2.4.2.5 Theatres/auditoria. Characteristics of this type of application are buildings, generally large in size, with high ceilings, low external loads, and high occupancy (producing a high latent gain and having a low sensible heat factor), which give rise to the requirements of large fresh air quantities and low operating noise levels. Theatres and auditoria may be in use only a few hours per day, and then in the evening after maximum outdoor temperatures of solar effects have occurred.

Air-conditioning is nearly always provided by the all-air type of system having the facility to take all fresh air for “free-cooling” when advantageous to do so, with equipment and controls arranged to handle light loads (partial occupancy), and to prevent relative humidity rising above a predetermined upper limit. Proper control of air distribution and avoidance of draughts is essential.

2.4.2.6 Residential buildings. Very few UK residences are air-conditioned. Some individual houses have unitary systems, and some luxury blocks of flats are provided with air-water systems. In this latter case, most of the considerations of 2.4.2.2 apply.

Some guidance on natural and mechanical ventilation of dwellings is given in CP 3:Chapter I(C).

2.4.3 Special applications

2.4.3.1 Hospitals/operating theatres. In many cases proper air-conditioning can be a factor in the therapy of the patient and in some instances part of the major treatment. For the majority of hospitals and operating theatres in the United Kingdom, reference may be made to the publications of the Department of Health and Social Security.

The main differences in application compared with other building types are:

- a) restriction of air movement between various departments and control of air movement within certain departments, to reduce the risk of airborne cross infection;
- b) a specific need for the ventilation and filtration equipment to dilute and/or remove particulate or gaseous contamination and airborne micro-organisms;
- c) close tolerances in differing temperatures and humidities may be required for various areas;
- d) the design should allow for accurate control of environmental conditions.

For a) and b) the air movement patterns should minimize the spread of contaminants as, for instance, in operating departments where the air flow should be such as to reduce the risk of periphery or floor-level air returning to the patient (owing to secondary air currents) whilst the general pressurization pattern should cause air to flow through the department from sterile to less sterile rooms in progression. In operating theatre suites a 100 % fresh air system is normally provided and air pressures in the various rooms are set by use of pressure stabilizers. Many types of air distribution pattern within operating departments are in use but generally they conform to high-level supply and low-level pressure relief or exhaust. There is also a need for a separate scavenging system for exhaled and waste anaesthetic gases both within theatre suites and where general anaesthetics may be administered. When zoning air distribution systems to compensate for exposure owing to building orientation and shape, consideration should be given to ensuring that the mixing of air from different departments is reduced to a minimum. This can be accomplished by the use of 100 % conditioned fresh air with no recirculation or, where recirculation is employed, by providing separate air handling systems for different departments based on the relative sensitivity of each to contamination (a degree of stand-by is provided by this system in that breakdown will affect only a limited section of the hospital). Where recirculated air is permitted, this should, of course, be coupled with proper filtering and disinfecting techniques.

Particular areas require specific treatment. For instance laboratories dealing with infectious diseases or viruses, and sanitary accommodation adjacent to wards, should be at a negative air pressure to any other area to prevent exfiltration of any airborne contaminants, and in extreme cases any exhaust to atmosphere should be passed through High Efficiency Sub-micron Particulate Air HEPA filters and/or sterilized. Operating theatres may contain around the operating table booths, curtained with plastic or having glass walls, in which air (recirculated within the theatre) is fed down through high efficiency filters above the table to give "laminar" flow down across the patient and out under the enclosing curtains or walling. Such arrangements have been found to give minimum bacterial count in the immediate vicinity of the operation wound site and are used where avoidance of cross infection is of critical importance.

2.4.3.2 Computer rooms. The equipment in computer rooms generates heat and contains components that are sensitive to sudden alterations and extremes of temperature and humidity as well as being sensitive to the deposition of dust. Exposure to conditions outside the prescribed limits can result in improper operation or the need for shut-down of the equipment. Manufacturers normally prescribe the conditions to be held. Typical conditions are air dry bulb, 21 ± 1.6 °C; r.h. 50 ± 5 %; filtration 80 % to BS 2831 test dust no. 1) or BS 3928.

A low-velocity recirculation system with re-heat is normally used with 5 % to 10 % fresh air make-up, which is allowed to exfiltrate from the room and ensure a positive internal pressure to prevent entry of dust and untreated air. The air distribution should be zoned to minimize temperature variations owing to fluctuations in heat load. Overhead air supply through ceiling plenums utilizing linear diffusers or ventilated ceilings is eminently suited to computer room application, permitting high air change rates to be achieved without undue discomfort to personnel. This arrangement may be used with either central or unitary air-conditioning plants. In addition to satisfying equipment requirements a well-designed overhead system is usually more satisfactory for comfort of personnel than a system using the floor void as a plenum and supplying cool air through grilles and extracting at high level, but some computer manufacturers design their equipment for this arrangement. In such cases the treated fresh air is introduced to the room at high level and sensible cooling only is performed by unit conditioners, placed around the room perimeter, extracting warm air at high level and returning cooled air to the underfloor void.

Background heating should be provided and controlled by a thermostat and a high limit humidistat to ensure reasonable environmental conditions in the event of shut-down or failure of the air-conditioning system.

The air-conditioning system should be reliable because failure to maintain conditions for only a short period may necessitate shut-down of the computer with a substantial monetary loss and possibly more serious consequences. The amount of standby plant installed, and the precautions taken, will depend on the particular circumstances.

2.4.3.3 Clean rooms. A clean room is a specially constructed enclosed area whose environment is closely controlled with respect to airborne particulates, temperature, humidity, air pressure, air flow pattern, air velocity and lighting.

Clean rooms are normally designated according to the maximum number of particles, of varying sizes from $0.5\text{ }\mu\text{m}$ to $25.0\text{ }\mu\text{m}$ allowable per cubic metre of a given air space. BS 5295 gives class 1, 2, 3 and 4 environments, which are designated in order of stringency of cleanliness.

To achieve these conditions a high standard of filtration using absolute or HEPA filters is required. The pattern of air flow is important, depending on the class and type of work, and can be categorized as conventional flow or unidirectional flow as follows.

a) *Conventional flow*. Air is supplied through conventional diffusers, flows generally downward and is removed near floor level. Using HEPA filters the contamination level can be reduced by 1.7×10^8 particles/ m^3 to between 1.7×10^6 particles/ m^3 and 3.4×10^6 particles/ m^3 . Nevertheless, airborne particles several hundred micrometres in diameter can still be present. The method does not afford protection from cross contamination.

b) *Unidirectional flow*. Air is introduced evenly from one entire surface of the room (such as the ceiling or a wall), flows at constant velocity across the room and is removed through the entire area of an opposite surface. Air velocities of 0.45 ± 0.1 m/s for horizontal flow and 0.3 ± 0.05 m/s for vertical flow are recommended.

The down-flow room consists of an entire ceiling of HEPA filters with a floor of open grating and provides the cleanest working environment at present available. It is also the most expensive in cost, but contamination can be reduced to less than 3×10^3 particles/ m^3 of a size $0.5\text{ }\mu\text{m}$ or larger.

The cross-flow clean room employs the same filtration technique except that the air flows from one wall to the opposite wall. Downstream contamination in the direction of the air flow will occur up to 6.7×10^5 particles/ m^3 at the dirty end of the room.

All unidirectional flow arrangements are applicable to work stations as well as entire rooms. In combination with conventional flow systems they can provide small areas with especially high degrees of contamination control.

All rooms should be maintained at static pressures sufficiently above atmospheric to prevent infiltration owing to wind or other effects (25 Pa is normally considered adequate). For certain processes, high heat output or noxious fumes may be exhausted direct to atmosphere and the necessary make-up air treated.

Humidity control is necessary to prevent corrosion, to prevent condensation on work surfaces, to eliminate static electricity, and to provide for comfort of personnel.

Close attention should be given to the construction and surface finishes of clean rooms.

Where possible, equipment requiring extensive servicing should be placed around the perimeter and an outside corridor provided from which maintenance can be carried out.

2.4.3.4 Laboratories. Requirements necessary for design determination are:

- a) internal and external conditions;
- b) thermal loads;
- c) time during which conditions are to be maintained;
- d) air flow rates;
- e) air flow patterns;
- f) contaminant control;
- g) sound and vibration limits.

The designer should obtain all necessary information and fully explain to the researcher the performance capabilities and limitations of the intended design. Very often, laboratories and test facilities require exhaust arrangements for the conveyance of contaminants to the atmosphere, and the exhausted air needs to be replaced by large quantities of fresh air. Selection of outdoor design conditions, therefore, materially affects the size and cost of heating and/or cooling facilities. The hours and seasonal periods during which specific indoor conditions are required to be maintained should be specifically expressed since they determine whether the spaces should be served by individual ventilation, air-conditioning and refrigeration systems operable at any time of the day or year or by central plants operating on common daily and seasonal schedules.

Laboratories handling toxic materials or dealing with flammable vapours are normally equipped with fume cupboards that are connected to an exhaust system. Various arrangements are available and details are given in the CIBS Guide and other technical literature. The exhaust system may be constant volume or variable volume; the former is simple to balance, highly stable and is flexible with respect to the number and location of hoods, but may mean high operating costs because of the large replacement air volumes to be handled and treated. In most laboratories it is unusual for all the fume cupboards to be operating together and operating economies can be achieved by use of a variable volume system that reduces the air flow when cupboards or hoods are not in use or when they may be operated at less than full capacity.

In some cases make-up air for fume cupboards that is not heated or cooled can result in reduced running costs. Attention should be paid to the manner in which the air is introduced to the room so that no draughts that will reduce the effectiveness of the fume cupboard are produced at the face of the cupboard. For more detailed recommendations see BS 3202.

Care should be taken where fumes are exhausted to atmosphere to ensure that they are well away from any supply air intake points and will be readily dispersed into the atmosphere. Normally this can only be achieved satisfactorily by discharging through a stack. The method will depend on the number of exhaust points and quantity discharged, the toxicity or nuisance value and height and location of the building.

In some cases the exhausted materials need to be filtered or passed through a scrubber to prevent undue pollution of the atmosphere.

2.4.3.5 Libraries, museums and art galleries. It is important that the required conditions are discussed with experts at the particular museum or art gallery.

The indoor air temperatures and relative humidity (r.h.) should generally conform to those laid down in 2.3 and the CIBS Guide, but in the case of museums and art galleries normally a close control of r.h. is required. Also, it is important that rapid changes of temperature or r.h. do not occur; a rate of change of 5 °C or 10 % r.h. in 1 h is considered excessive. Since one of the principle reasons for installing air-conditioning in these buildings is the preservation of the contents, the plant will be running on a 24 h basis, and, when assessing the standby plant to be installed, the value of the contents being protected should be taken into account.

Air filtration, particularly in cities, is important and should generally be not less than 95 % to BS 2831 (test dust no. 2). Atmospheric pollution by SO₂ or SO₃ can be very injurious to paintings, old silver, etc. There is therefore a need to install scrubbing plant or carbon filters to extract such contaminants though even these may not provide the desired levels of purity.

Generally, all-air systems should be used to ensure adequate control of humidity, and where there are considerable variations in internal load (e.g. numbers of visitors) a variable volume system should prove the most economical solution.

A low noise level is obviously desirable, about NR 35 being reasonable.

2.4.3.6 Industrial ventilation. In industrial buildings ventilation is needed to provide the fresh air normally required for health and hygiene; use of natural or mechanical ventilation depends on the building configuration, the process, the number of personnel, etc. Frequently the movement of relatively large quantities of air, above normal hygiene needs, is required to remove heat emanating from process plant, to give increased air movement across the skin (increasing the sweat evaporation rate to give some degree of comfort), or to remove toxic or unpleasant fumes or vapour or dust.

These situations may be met by various combinations of general and local mechanical ventilation, with various arrangements for supply and exhaust air, as detailed in 3.1.1.

The following are some of the factors that should be considered in the system design.

- a) A supply system is not normally satisfactory without a complementary exhaust system and similarly any exhaust system requires "make-up air" that in low ambient temperatures should be tempered to avoid cold draughts.
- b) The method of supply air distribution through grilles or diffusers should not give rise to uncomfortable air currents. Directional grilles, diffusers and nozzles designed specifically for industrial relief systems are commercially available.
- c) Exhaust hoods and canopies should be designed to capture the unwanted fumes or dust irrespective of other air currents in the vicinity.
- d) Because of the normally large volumes of ventilation air required all means of heat recovery should be considered. (See 3.1.3.2.)

For control of contamination by gases, fumes and dusts, local exhaust systems will be suitable where the contamination originates at concentrated areas and is characterized by low or imperceptible air motion, requiring a capture velocity exceeding 0.14 m/s. High capture velocity with low air volume is desirable.

A system employing the dilution method will usually be indicated where the contaminant originates at scattered points dispersed generally throughout the area. Except for low rates of liberation of fumes, dilution ventilation requires such high volumes of air, without giving positive assurance of safety, that such systems should be used only as a last resort. A combination of local exhaust and dilution methods is often economical since well designed exhaust hoods or openings removing the bulk of the contamination will greatly reduce the air volumes required for dilution purposes.

Where dusts or fumes mixed, with air can produce explosive conditions it is essential that precautions such as the inclusion of pressure relief vents be taken. Reference should be made to publications of the Health and Safety Executive, and to relevant statutory requirements considered in 2.5.

In the case of dust and fumes, the Guidance Notes of the Health and Safety Executive specify the threshold limit values (TLV's) for a wide range of chemical elements and compounds. The TLV of a substance is the concentration in air that, if exceeded, may be injurious to health.

2.4.3.7 Industrial air conditioning. The requirement for air-conditioning in industrial situations is normally connected with the process requirements. There may be a need, for instance, for controlled humidity conditions combined with some temperature control. The system employed will vary with the requirements of the application, type of building, etc., and no general guidelines can be laid down.

2.5 Statutory regulations/safety considerations

2.5.1 Authorities and approval of schemes. A ventilation or air-conditioning system should comply with the requirements laid down in the current statutory legislation or any revisions currently in force, and consideration should also be given to any relevant insurance company requirements.

Compliance with this code is not automatically deemed to satisfy statutory and legal requirements.

The following are the principal statutes concerned:

The Building Regulations 1976

The Building Standards (Scotland) Act 1970

Clean Air Act 1968

Control of Pollution Act 1974

Factories Act 1961

Fire Precautions Act 1971

Health and Safety at Work etc. Act 1974

London Building Acts (Amendment) Act 1939

Offices, Shops and Railway Premises Act 1963

Water Act 1973

2.5.2 Fire and safety considerations

2.5.2.1 Design principles. The installation of mechanical ventilation and air-conditioning systems may affect the fire risk within the building, both as regards structural protection and means of escape in case of fire, and may influence any necessary fire venting or fire fighting considerations.

The extent and detail of statutory control and other specialist interests may vary considerably according to the design, use, occupation and location of the building, and the type of system of mechanical ventilation and air-conditioning proposed. It is particularly important that the appropriate authority be fully consulted at an early stage.

The degree of control and the requirements imposed vary according to the circumstances of the case, depending on whether the control concerns means of escape (e.g. clearance of smoke in the event of fire), structural fire precautions (e.g. maintenance of structural fire separations), health of the occupants, conservation of energy, or any combination of these. Full details may have to be approved by the local authority in such cases as:

- a) buildings controlled from the point of view of the means of escape (i.e. most buildings except dwelling houses) where recirculation of air is involved and/or where pressurized staircases are contemplated as part of the smoke control arrangements;
- b) places of public entertainment;
- c) flats and maisonettes where mechanical ventilation is necessary to lobbies and corridors as part of the smoke control arrangements;
- d) large garages, motor repair shops and car parks, hotels, parts of buildings used for trades or processes involving a special risk, and departmental stores and similar shop risks in large buildings;

e) buildings within the scope of the London Building (Constructional) Bye-laws 1972 where mechanical ventilation is intended to supplement or take the place of the required minimum natural ventilation (such as in “sealed” buildings and underground rooms).

Reference can be made to CIBS Technical Memoranda 1 and 2, BS 5588-4, and CP 3:Chapter IV (itself or its separate Parts, as relevant).

2.5.2.2 Structural considerations. Where consideration is being given to the installation of equipment within buildings, a check should be made of the capability of the building to support the weight of the equipment. This check should include the route taken by the equipment to its final position. There should also be access from the road to the position selected for the plant. This access should include space for any crane lifts or for turning of delivery transport.

2.5.2.3 Independent systems. Certain areas of a building require separate and independent mechanical ventilation systems. These areas include:

- a) staircases for control of smoke;
- b) residential accommodation;
- c) boiler chambers;
- d) areas containing oil-immersed electrical plant;
- e) lavatories, garages and car parks, certain trade uses.

For information concerning the design of systems for these areas, reference may be made to the CIBS Guide.

Extract systems from kitchen equipment should be separate from any other and the extracted air should not be recirculated. Where a fish fryer is used no fire dampers should be fitted in the ventilation extract duct unless any statutory requirement exists otherwise but adequate cleaning facilities should be provided. Canopy, ducting and lagging should be made from non-combustible material. Where ducting passes through other floors between the kitchen and the external weathering cowl, it should be enclosed in fire-resisting construction at least equal to the standard of fire resistance required in that floor.

2.5.2.4 Fresh air quantities. Certain legal requirements exist regarding the supply of fresh air to ventilation and air-conditioning plants. Section 7 of the Offices, Shops and Railway Premises Act, requires certain quantities of fresh air to be supplied by the ventilation system: these are given by Guidance Note no. 19 of the Health and Safety Executive; see also the London Building (Construction) Bye-law 1972 for the Inner London area.

Care should be taken when positioning air intakes to prevent the intake of contaminated air; see **2.3.3.1**. Discharges should be positioned where they will not cause problems from smells, etc.

2.5.2.5 Ductwork and enclosures. All ductwork should be constructed from non-combustible materials. In special circumstances it may be necessary to use plastics ductwork. In such cases additional measures may be required and advice of the building authority should be sought.

Any duct, the interior of which is liable in normal use to accumulate dust, grease or other flammable matter, should be provided with adequate means of access to facilitate cleaning and inspection.

As far as practicable, flexible joint connections should be avoided.

Considerable information on fire precautions for ventilation ductwork, including flexible connections, dampers and duct enclosures, is given in Appendix A of CP 413. Further information relating to fire dampers is given in **4.3.1.3** and **4.3.2.3**.

2.5.2.6 Thermal and acoustic insulation. To reduce the spread of fire or smoke by an air-conditioning system, care should be taken with the choice of materials used for such items as air filters, silencers and insulation both internal and external. These materials should be tested for surface spread of flame to BS 476-7 and should satisfy the relevant recommendations of CP 413 and the requirements of any relevant Building Regulations and standards.

Some authorities require prior approval of any thermal and acoustic materials used in air-conditioning systems unless such materials are wholly non-combustible. See CP 413, BS 5422, CIBS Guide Section B5 and CIBS Technical Memorandum No. 1.

2.5.2.7 Mechanical equipment. All mechanical equipment associated with either ventilation or air-conditioning plants should be installed to comply with the standards required by HM Factories Inspectorate and relevant Building Regulations or British Standards.

2.5.2.7.1 Fans. Fans should be installed such that they will operate in an entirely safe manner. Proper guards should be provided around belt drives; see BS 5304.

2.5.2.7.2 Refrigeration. When installing refrigeration equipment for air-conditioning, reference should be made to BS 4434. This standard refers to the types of refrigerants that are permitted for use in air-conditioning systems for human comfort and covers the requirements for the plant room containing the refrigeration plant, access doors, ventilation of plant room and the materials that should be selected for construction of the plant. It is not desirable for refrigeration plant to be installed in the same room as a boiler.

2.5.2.8 Electrical equipment. Any site-installed electrical work in connection with the installation of ventilation or air-conditioning plant should comply with the current edition of "Regulations for the Electrical Equipment of Buildings", published by the Institution of Electrical Engineers.

Means of isolation should be provided adjacent to all remotely controlled electrical apparatus especially when motors are involved.

All electrical equipment associated with either ventilation or air-conditioning plants should be installed to comply with the standards required by HM Factories Inspectorate, relevant Building Regulations and Building Standards, and with the Electricity Supply Regulations.

2.5.2.9 Gas/oil-fired equipment. The installation of gas/oil-fired air heaters should comply with the Building Regulations and Building Standards. Direct-fired heaters may require a relaxation of Building Regulations and the local authority should be consulted.

Special attention should be given to the flueing and to the provision of combustion air and ventilation of the area containing the heater. (See CIBS Practice Notes 1 and 2.)

2.5.2.9.1 Oil-fired air heaters. Oil-fired air heaters should be installed to comply with the recommendations of BS 5410 to prevent the risk of fire or minimize the spread of fires from heater or oil storage tanks. Protection of the tank and heater may require either the provision of manual and automatic shut-off valves to shut-off oil supply or the provision of daily service tanks.

2.5.2.9.2 Gas-fired air heaters. Gas-fired air heaters should be installed to comply with the recommendations of the Gas Safety Regulations and with the following codes of practice:

- CP 331-3
- CP 332-4
- BS 5440.

Heaters should preferably be selected from the British Gas list of Approved Commercial Appliances.

2.5.2.10 Fire and smoke detection. When the system involves the recirculation of air, consideration should be given to the installation of detection devices that would either shut off the plant and close dampers or discharge the smoke-laden air to atmosphere. Detectors may be advisable in certain circumstances even when the system is not a recirculatory one. Discharges should not be positioned near to fire escapes, main staircases or where they could be a hindrance to the work of fire authorities. The local Fire Authorities (and possibly Building Control) should be consulted.

A careful study of the operating characteristics of each type of sensing device should be made before selection. Smoke detectors are normally either of the optical or ionization chamber type. These can be used to either sound an alarm system or operate a fire damper or a series of fire dampers. Care should be taken with their siting as various factors affect the satisfactory operation.

Ionization type detectors are sensitive to high velocity air streams and if used in ductwork the manufacturer should be consulted.

Some authorities have regulations regarding the installation of smoke detectors and these require the detector to:

- a) stop the input fan;
- b) close a damper in the return air duct;
- c) cause the smoke-laden air to be discharged to atmosphere;
- d) operate a suitable alarm system.

In the above instances the appropriate controls would require manual re-setting. Care should be taken if the supply fan is stopped as this can cause smoke to be circulated around the building in the supply ducting.

The Fire Research Station publish a number of notes on the control of smoke and fire within various types of building. Where they exist they should be consulted for details of smoke trapping, control and smoke removal.

See also CP 413 and BS 5588-4.

2.5.2.11 Smoke control. While it is essential that the spread of smoke through a building be considered in the design of fire protection systems for all types of applications, it assumes particular significance in high rise buildings, because the time necessary for evacuation may be greater than the time for the development of untenable smoke conditions on staircases, in lift shafts and in other parts of the building far away from the fire. Lifts may be filled with smoke or unavailable, and, if mass evacuation is attempted, staircases may be filled with people.

Most fire authorities now require that one or more “escape staircases”, connecting to outdoors at ground level, should be maintained sufficiently free of smoke, to enable mass evacuation of high rise buildings.

Smoke may spread to areas outside a fire compartment owing to expansion (resulting from the temperature effects of the fire), the stack effect (caused by the outside-inside temperature difference), the wind effects, and the transfer around mechanical ventilation and air-conditioning systems. In particular, central systems have a potential for spread of smoke far beyond the origin of the fire. For this reason, many Regulations and fire authorities require that fan systems are turned off automatically when excessive smoke or temperature rise is sensed at some point in the building or in the ductwork system. Even in these circumstances, smoke dampers may be necessary to prevent the migration of smoke through the ductwork system and around the building.

Therefore, all air-handling systems of a building should be designed with fire protection and smoke control in mind incorporating, where appropriate, facilities to permit their operation for the control of smoke within the building in event of fire.

There is little experience with design of systems for smoke control or with their performance under real or simulated fire conditions. Their design requires that considerations be given to anticipation of the fire and smoke situations that may occur, recognition of the mechanism of smoke movement, knowledge of building air leakage and stack effect characteristics, and careful definition of smoke control objectives.

One method of using mechanical ventilation for smoke control favoured by many fire authorities is the positive pressurization of escape routes, principally escape staircases in high rise buildings. The use of pressure-controlled, ventilated lobbies may be required, in addition.

The pressurization systems for staircases use large volumes of outside air, preferable preheated in winter. The systems may be arranged to operate continuously at low speed, being increased to high speed in the event of fire, or arranged to operate only in emergency. Noise and draughts are not considered a problem in an emergency situation. Fans, starters and cabling should themselves be protected from fire and connected to an emergency electrical supply.

2.5.2.12 Firemen’s switches. A means of control for the use of firemen should be provided to enable such parts of the mechanical ventilation and air-conditioning system as may be needed to be controlled in an emergency. The control should be in a glass-fronted box or otherwise so as to be accessible but protected to prevent operation by unauthorized persons. The control should be marked: “VENTILATION EMERGENCY CONTROL” and the “OFF” position clearly marked. The siting of firemen’s switches should be discussed with the local Fire Authority.

2.5.2.13 Special applications. Where areas of a building are ventilated or air conditioned for special purposes, such as computing or printing rooms, etc., there may be a need to take special measures to protect operating or maintenance staff working on the air-conditioning and associated plants. These can take the form of special alarm systems and means of escape and are particularly important where automatic fire extinguishing equipment is installed.

2.5.2.14 Operation/maintenance. Clear, brief instructions to the correct operating procedure for air-conditioning plant should be permanently displayed in the appropriate position. The installation should be under the regular supervision of a competent person.

The plant should be maintained in an efficient manner at all times while all or any part of the building is occupied.

Where the ductwork is liable to be contaminated internally with grease, dust, lint, etc., adequate means should be provided for regular cleaning and consideration given to the necessity of providing fire fighting facilities to combat a fire within the ductwork system. Any fire fighting equipment should be checked at regular intervals.

Regular checks should be made by the maintenance personnel to see that extracts for contaminated discharge or air from nearby buildings, etc., have not been sited near to any existing air-conditioning air intakes (see 2.3.3.1).

Adequate maintenance should be given to all smoke detectors, smoke control dampers, fire dampers, firemen's switches and controls (see CP 413); particular care should be taken in industrial and other atmospheres where rapid accumulation of dust could impair the effectiveness of detectors or dampers. If gas detectors are installed they should be checked and serviced regularly.

2.6 Energy conservation and energy management

2.6.1 General. In the context of this code, energy conservation signifies the optimum use of energy to operate the ventilation and air-conditioning system of a building. Not always will this mean the minimum use of energy.

It is axiomatic that general standards of comfort or particular environmental requirements within the building should not be sacrificed in an endeavour to achieve a low consumption of energy. Similarly nothing in this code overrides regulations related to health and safety.

Although attention is drawn to specific aspects of energy conservation in this section of the code, it should be understood that a requirement for effective utilization of energy was a precondition when drafting each of the other sections.

It is intended that the code be somewhat flexible, so that designers are encouraged to adopt an innovative approach.

2.6.2 Energy targets. For the purpose of assessing energy conservation efficiency of one system design against another, or in an existing building comparing one period of energy use against another, target consumptions may be established.

2.6.2.1 Demand targets. Energy demand is mainly determined by location of the building, its structure and the equipment installed within it. Demand targets are readily applied to designs for new buildings and their services and are quoted as an "average rate" of energy use (W/m^2).

2.6.2.2 Consumption targets. The energy actually consumed in a building is, in addition, determined by the manner in which the building and its services are used and is measured in units of energy (J/m^2). Targets may be established according to varying climatic conditions and varying patterns of building use.

2.6.3 Guidance. For more detailed treatment of the determination of heating and cooling consumption and the design and control requirements for general comfort applications in new buildings and the operation of existing buildings, reference should be made to the "Building Energy Code" produced by the Chartered Institution of Building Services.

2.6.4 Air-conditioning/ventilation. Some of the more important aspects of establishing energy conservation requirements for ventilating and air-conditioning systems are given below.

2.6.4.1 Systems

2.6.4.1.1 The design of the system and its associated controls should take into account the following:

- a) the nature of the application;
- b) the type of construction of building;
- c) external and internal load patterns;
- d) the desired space conditions;
- e) permissible control limits;
- f) control methods for minimizing use of primary energy;
- g) opportunities for heat recovery;
- h) economic factors (including probable future cost and availability of fuel).

2.6.4.1.2 The operation of the system in the following circumstances should be considered when assessing the complete design:

- a) in summer;
- b) in winter;
- c) in intermediate seasons;
- d) at night;
- e) at weekends;
- f) under frost conditions;
- g) if electricity supply failure occurs and when the supply is restored.

2.6.4.1.3 Consideration should be given to changes in building load and the system designed so that maximum operational efficiency is maintained under part load conditions. Similarly, the total system should be separated into smaller increments having similar load requirements so that each area can be separately controlled to maintain optimum operating conditions.

2.6.4.1.4 The temperatures of heating and cooling media circulated within the system should be maintained at the level necessary to achieve the required output to match the prevailing load conditions with the minimum expenditure of energy.

2.6.4.1.5 The energy used for the transport of air and water within the system should be assessed and transport factors should be not less than those quoted in the CIBS Building Energy Code.

2.6.4.1.6 Recovered energy should be used as much as possible.

2.6.4.1.7 Operation and maintenance procedures should be properly planned.

2.6.4.2 Equipment

2.6.4.2.1 All equipment and components should be tested in accordance with the relevant British Standards; where no applicable standard exists, an agreed international or other standard and test procedure may be applied.

2.6.4.2.2 The equipment suppliers should furnish upon request the energy input and output of the equipment, which should cover full and partial loads and standby conditions as required in order that the energy consumption can be assessed over the whole range of operating conditions.

2.6.4.2.3 Where components from more than one supplier are used or where the components of a single supplier are used in a combination for which published performance data does not exist then the system designer should take the responsibility for ensuring that their function leads to optimum energy use.

2.6.4.2.4 Coefficients of performance ascribed to various items of equipment should not be less than those quoted in the CIBS Building Energy Code.

2.6.4.2.5 Equipment which requires preventative maintenance should be furnished with all the necessary information.

2.6.4.3 Control/system. The designer should aim to select the simplest system of control capable of producing the space conditions required. It is uneconomical to provide controls with a degree of accuracy greater than that required by the application. Consideration should be given to the provision of centralized monitoring and control, thus achieving optimum operation (see 3.4.2). Detailed application of controls is given in 3.4.

Section 3. Design considerations

3.1 Types of system

3.1.1 Ventilation systems. In the interest of efficient use of energy and comfort of the occupants, it is imperative that all systems of ventilation should be considered in relation to the thermal characteristics of the building.

3.1.1.1 Mechanical extract/natural supply. The simplest form of extract system comprises one or more fans, usually of the propeller, axial flow or mixed flow type, installed in outside walls or in the roof. The discharge usually terminates in louvres or a cowl or a combination of both.

Alternatively, the system may comprise a range of ductwork arranged for general extraction of the vitiated air or for extraction from localized sources of heat, moisture, odours, fumes and dust. Such ductwork may be connected to centrifugal or axial flow fans that discharge through the wall or roof, terminating in louvres or cowls or a combination of both. The ductwork includes suitable extract points and dampers.

It is essential that provision for replacement air be made and consideration given to the location and size of inlet.

An extract system should be regarded as a palliative measure to meet the need for ventilation in particularly crowded rooms, offices or restricted areas in which local conditions are likely to prove objectionable as, for example, in lavatories, kitchens, plant rooms and sections of workshops or laboratories; or where there is a statutory requirement for ventilation.

3.1.1.2 Mechanical supply/natural extract. This system is similar in form to the extract system but arranged to deliver fresh air into the enclosed space. Such a system necessitates provision for the discharge of vitiated air by natural means. Where there is a requirement for the enclosed space to be at a slightly higher pressure than its surroundings (to exclude dust or smoke, for example), the discharge may be through natural leakage paths or balanced pressure relief valves, as may be required.

A ducted supply system will normally include an air-cleaning device and an air heater battery with automatic air temperature control. Ducted supply systems can provide better control of air movement and reasonable control of comfort conditions.

3.1.1.3 Combined mechanical supply/extract. This system is a combination of those described in 3.1.1.1 and 3.1.1.2 and comprises supply and exhaust ductwork systems or may employ a common fan with a fresh air inlet on the low pressure side. In the latter case, an interconnection may be provided to allow partial or full recirculation as required. The fresh air input side of such systems will normally be provided with an air filter and an automatically controlled air heater battery. The ductwork will include suitable dampers, grilles and diffusers.

As with ducted supply systems (see 3.1.1.2), combined supply and extract systems can provide better control of air movement and reasonable control of comfort conditions.

3.1.2 Air-conditioning systems. Systems for air conditioning are basically similar to the ventilation systems described in 3.1.1, but the need to control temperature and humidity within predetermined limits throughout the year demands the facility for heating, humidifying, cooling and dehumidifying.

Various types of refrigerating systems are available to accomplish the tasks of cooling and dehumidifying, which are an essential feature of air conditioning (see 3.1.3.1). Systems of air conditioning may be conveniently grouped as all-air type, air-water type or unit type.

3.1.2.1 All-air systems. In the all-air type of air-conditioning system, the total heating and cooling load is catered for by controlling the supply air condition. Most plants operate on the recirculation principle, where a percentage of the air is extracted and the remainder mixed with incoming fresh air.

Low velocity or high velocity systems may be used, the latter requiring smaller ducts; however, fan energy is greater, careful acoustic treatment is essential, and higher standards of duct construction are needed.

3.1.2.1.1 Constant volume. Accurate temperature control is possible, according to the system adopted. Low velocity system variations include dehumidification with return air bypass, and multizone (hot deck/cold deck mixing). High velocity systems may be single or dual duct type.

The dual duct system uses two separate supply ducts, one carrying cold air, the other hot air, which are mixed in a terminal device (4.3.1.2.1) in the correct proportions in each space as dictated by individual room thermostats. Good temperature control of each space is provided, and, according to the particular plant layout adopted (e.g. all-air dehumidified), reasonable control of the average level of zone humidity may be achieved. Both capital and operating costs tend to be high compared with other systems.

3.1.2.1.2 Variable volume. Most UK conditioning systems operate at partial load for most of the year and the variable air volume (VAV) system is able to reduce energy consumption by reducing the supply air volume to the space under low load conditions. The VAV system is often arranged for cooling only, serving internal zones, or external zones in conjunction with a conventional heating system. Good temperature control is possible but care should be taken at partial load to ensure adequate fresh air supply and satisfactory control of air distribution and space humidity. Both single duct and dual duct VAV terminals are available (4.3.1.2.1).

3.1.2.2 Air/water systems. Control of conditions within the space is achieved by initial control of the supply air from a central plant but with the main and final control at a terminal unit within the conditioned space. The supply air provides the necessary ventilation air and a small part of the total conditioning. The major part of the room load is balanced by water through a coil in the terminal unit, which can be either a fan coil unit or an induction unit.

Depending on the degree of control required, the water-circulating system can be either of two, three or four pipe arrangement. With two pipe circulation a single flow and a single return circulate hot or chilled water as required. Such a system can only provide heating or cooling to the system on a changeover basis, so it is ineffective where wide modulations of conditions over short periods are required. The installed cost, however, is naturally the cheapest of the circulation systems. The three pipe system is a way of overcoming the disadvantages of the two pipe system without raising the installed cost too high. In this system a separate hot water flow and chilled water flow is taken to the terminal units but a common return is taken from them to the plant room. The best system from a control point of view is the four pipe system, where separate hot water and chilled water flows and returns are taken from the plant room to the terminal units. Although the most expensive method of circulating the water, it is the only satisfactory one if reasonable control is required.

3.1.2.2.1 Fan coil system. In the simplest layout, the units may be located against an outside wall with a direct, fresh air connection. A superior arrangement utilizes a ducted, conditioned, fresh air supply combined with mechanical extract ventilation.

Control of unit output may be achieved by fan speed and/or water flow/temperature control. Electric power is required at each terminal unit.

3.1.2.2.2 Induction system. High velocity air forced through jets in the terminal units induces room air into the unit and across the coils. Unit output may be controlled by water flow or air bypass arrangements.

3.1.2.3 Unit systems. Such systems are usually those incorporating one or more units or packaged air-conditioners having a direct expansion vapour compression refrigeration system. Similar units using chilled water from a central plant would be designated fan coil systems. Most units are only suitable for comfort application but specially designed units are also available for process and industrial applications.

3.1.2.3.1 Single units. Where the application is comparatively small a single unit will be sufficient; this can be either a room conditioner designed for a single area or a roof top or void unit that can serve several spaces by means of a ducting system. The system is complete and normally does not require connecting to a central plant room. The heating can, however, be provided by a coil in the unit, which will need connecting to a heat source.

3.1.2.3.2 Multiple units. In large applications units can be used in multiples to serve one large space or a number of smaller individual spaces. Consideration should be given to the availability of unit locations and the maintenance required. A multiple system can be so arranged that a common condenser water-cooling system can be connected to a large cooling tower for heat rejection and a heat source providing water to individual hot water coils.

3.1.3 Special systems for subsystems

3.1.3.1 Refrigeration systems. Two methods of refrigeration are currently in common use for air-conditioning systems. These are the mechanical (vapour compression) system and the absorption (heat operated) system. Types of refrigerating equipment are described in 4.10.

3.1.3.1.1 Vapour compression systems. The mechanical vapour compression cycle utilizes the evaporation of a liquid refrigerant to absorb heat and lower the temperature at the evaporator. The compressor pumps this gas at high pressure to the condenser where the refrigerant vapour is liquefied and rejects heat to raise the temperature of its surroundings. A throttling device or expansion valve meters the flow of liquid refrigerant to the evaporator.

a) *Air cooling.* The evaporator is mounted directly in the air stream to be cooled and may be part of a built-up system or a unitary or room air conditioner. Air-cooling coils of the direct expansion type are described in 4.6.1.1.2.

b) *Liquid chilling.* The evaporator is used to chill liquid, usually water, in a heat exchanger that may be one of the types described in 4.10.1.1.1.

3.1.3.1.2 Absorption systems. The absorption cycle uses a solution that by absorbing the refrigerant replaces the function of the compressor. The absorbent/refrigerant mixture is then pumped to a higher pressure where the refrigerant is boiled off by the application of heat, to be condensed in the condenser.

Absorption machines are used in liquid-chilling applications and are described in 4.10.1.2.

3.1.3.2 Heat recovery systems. A heat recovery air-conditioning system reclaims internal building heat, raises its temperature to a usable level, and redistributes this energy to perform useful heating in other areas.

A properly designed “balanced” system operates during all periods of the year to utilize all internal heat before taking heat from an external source such as a boiler. When an excess of internal heat is available this may be stored or rejected to outside. Under severe winter conditions, at nights or weekends, or at start-up there may be insufficient internal heat available, which requires heat to be provided by an external source.

Heat recovery systems typically employ multi-pipe hot and chilled water distribution circuits serving air-water systems of the induction or room fan-coil type. All-air systems, preferably using variable air volume distribution, and employing wide-range coils, may also be arranged for heat recovery.

Heat recovery may be obtained from refrigeration machines with reciprocating, screw or centrifugal compressors. Either standard condensers combined with plate exchangers or double or triple-bundle condensers may be used.

It should be noted that only low grade heat is obtainable as high condenser water temperatures will increase the consumption of power of the machine, and an economic balance should be sought.

Various types of heat recovery equipment are described in 4.12.1.

3.1.3.3 District cooling systems. For very large projects, e.g. with a total refrigerating capacity above 10 MW, the centralized type of plant can take advantage of the large diversity usually found when many different buildings or air-conditioning systems are connected to a common chilled water distribution circuit.

Advantages include the use of larger and more efficient refrigeration machines with lower cost per kW of cooling, generally both as regards capital and operating costs; easier operation and maintenance; longer equipment life; less total plant space required; less noise and vibration in occupied areas; simplified cooling tower and electrical distribution and automatic control arrangements; inherent standby capacity and operating flexibility.

Particular attention should be paid to accurate determination of daily and annual load profiles, to the economics of chilled water pumping (optimum flow rates and temperature differentials), to best arrangement of refrigeration equipment (series, parallel or combinations), and to terminal control arrangements. Also extremely important is correct choice of piping materials, valves, and thermal insulation, and proper consideration should be given to support and expansion/anchor arrangements, and to corrosion control methods (3.6).

3.1.3.4 Building-integrated systems. A variety of air-conditioning systems, many of them proprietary, have been developed to permit a fully integrated design with the building, architectural, structural and electrical systems.

3.1.3.4.1 Modular systems. A predetermined module size is used to determine the design and location of air-conditioning terminals and room units, light fittings, telephone points, electrical outlets, etc., for open plan layouts with a view to minimizing modifications to services when partitioning layout is initially established or subsequently varied. The air distribution system may use ceiling air terminals, integrated air/light fixtures, or a combination of both.

3.1.3.4.2 Floor systems. These generally combine elements of the structural, mechanical and electrical systems, and may utilize perforated steel duct or panels, or the concrete floor itself, for air distribution. Particular attention should be paid to load calculations, condensation control and fire precautions.

3.1.3.4.3 Ventilating ceiling systems. Also termed plenum supply systems, these are described in 4.3.1.1.

3.1.3.4.4 Precoordinated building subsystems. These have been developed using a "Systems approach" design technique, which interrelates manufacturers' components (structural, lighting, HVAC, etc.) to determine their compatibility from a functional and dimensional standpoint, the air being to carry out as much as possible in the factory and reduce site operations to a minimum.

3.1.3.5 Panel cooling systems. Radiant panel systems are generally of the perforated metal, suspended, acoustic type with a pipe coil bonded to a metal face sheet. Panel systems may be used for summer cooling and winter heating, and arranged in small groups to provide good zone control, or as a large continuous area of maximum economy. Good comfort levels may be achieved with radiant loads treated directly, and with normal ventilation and air velocities in the occupied space. In some cases, wall, floor and structural arrangements may be simplified. Particular care should be taken in system design and operation to avoid condensation problems.

3.1.3.6 Total energy systems. The term "total energy" usually describes an on-site electrical generating system that is arranged to achieve maximum utilization of the input energy by salvaging the waste heat from the generating process.

A total energy system uses a prime mover (reciprocating engine or a turbine), a generator, and a waste heat recovery system. Prime movers are described in 4.13.

Very careful technical and economic analyses of heating, cooling, electrical, and possibly domestic hot water, load profiles are required before the decision to use a total energy system can be justified. The most economical arrangement may be complex and include, for example, steam-turbine driven centrifugal water chillers with pass-out steam serving absorption machines, and incorporating waste heat boilers.

3.2 Basis of design. Establishing the "basis of design" is the first important step in designing an air-conditioning or ventilation system. In the case of air-conditioning, it is essential that the system be able to be integrated successfully with the space or building served, and with all the other mechanical and electrical systems within that building.

3.2.1 System requirements. An air-conditioning system should normally be capable of satisfying the following requirements.

3.2.1.1 External load variations. The system should be able to cope with the daily and annual variations in outdoor temperature, humidity, wind and solar radiations.

3.2.1.2 Internal load variations. The system should be able to handle the internal load variations owing to movement of people, and operation of lights, machines and equipment.

3.2.1.3 Operating variations. The system should be able to:

- a) satisfy the maximum heating and cooling loads, and operate as required under partial load conditions including at night and over weekends and to provide frost protection, if required;
- b) handle sensible/latent heat load ratios that may be different from (and more severe than) those occurring at maximum design conditions;
- c) operate at all times to provide adequate ventilation, without causing draughts or stuffiness, and with noise and vibration below the established design criteria.

3.2.2 The external environment. The following factors should be considered, detailed information being given in the CIBS Guide.

3.2.2.1 External design temperature and humidity. These conditions should be selected with regard to local weather data, economic considerations, and the effects of departure from inside design conditions caused by extreme weather variations.

3.2.2.2 Wind. Infiltration loads (sensible and latent) owing to leakage of unconditioned air into the building should be determined according to records of wind velocity and direction, and consideration of building orientation, arrangement and construction.

3.2.2.3 Solar radiation. The amount falling on the building depends on its geographical location, altitude and orientation, and varies both hourly and from day to day throughout the year. This amount may be modified by local atmospheric effects (e.g. industrial haze), by shading of adjacent buildings, or by nearby reflective surfaces (e.g. water).

3.2.2.4 Pollution and noise. Local atmospheric pollution should be taken into account in the establishment of desired internal air cleanliness and filtration standards. External road traffic noise and contaminants, and aircraft noise, may have a bearing on the design of air intakes or exhaust points.

3.2.3 The internal environment. Factors to be considered include dry bulb temperature and relative humidity, surface temperatures of the enclosure, air purity, air motion (both velocity and direction), ventilation air quantity, noise and vibration, interactions with lighting (also colour), communications systems and space distribution, and permitted tolerances on design values. The most important of these comfort factors are dealt with in 2.3.

3.2.4 The building fabric. The outer shape of the building to be air-conditioned generally has a major influence on the nature and size of that part of the load attributable to external effects. Factors to be considered include: materials and thicknesses of walls, roofs, ceilings, floors and partitions, and their relative positions in the structure; thermal and vapour transmittance coefficients; areas and types of glazing, external building finishes and colour (which affect the load owing to solar radiation); shading devices at windows, overhangs, etc. (which reduce solar radiation and light transmission).

It is important to distinguish between the instantaneous heat gain from external effects (the portion of these loads that enters the conditioned space) and the *actual* thermal load (the cooling load that the air-conditioning system has to handle).

The actual load is less than the instantaneous gain, owing to the heat storage of the building fabric. Methods of computing this load are given in the CIBS Guide.

3.2.5 Internal loads. These loads may be sensible and/or latent gains. Typical sources of internal loads include occupants, lights, machinery, equipment and appliances, products, adjacent spaces and the air-conditioning system *itself*. Data for estimating purposes is contained in the CIBS Guide.

3.2.5.1 Occupants. Heat and moisture liberated by occupants depends on surrounding environmental conditions and activity level (metabolic rate).

3.2.5.2 Lights and machinery. Heat from lighting fixtures depends upon lamp type (e.g. incandescent, fluorescent), fixture type (e.g. surface-mounted, recessed) and any special features, which may include provision for air supply or extraction through the fitting. With fluorescent fixtures, the heat from the control gear should be included.

Heat and moisture from machinery, equipment and appliances should be carefully evaluated, due allowance being made for diversity, difference between actual motor input and name plate data, etc. Certain loads may be minimized by use of local ventilation or exhaust hoods.

3.2.5.3 Other loads. Heat liberated by steam or hot water piping passing through conditioned spaces, water evaporated from open tanks, etc. are load sources.

In process or product applications, heat and moisture liberated from, or absorbed by, substances and materials (e.g. food, paper, textiles) should be carefully estimated.

Heat and moisture may be transferred from adjacent unconditioned spaces by transmission through the building structure, and by movement of air.

3.2.5.4 System gains. Heat and moisture transfer may take place to or from the air-conditioning system. One major source is heat pick-up from the air-conditioning fans or pumps, which transfer a portion of their energy to air or water circuits (ideally, this transfer should be limited: see discussion of energy conservation requirements in 2.6). Additionally, on the cooling cycle, heat may be transferred to supply and return ducts passing through unconditioned spaces. Cooling effect may be lost by leakage of conditioned air from supply ductwork; leakage of unconditioned air into return ductwork may add to the cooling load. During winter, heat losses and duct leakage increase the system heat requirements.

3.2.6 Ventilation rates/infiltration. The amount of unconditioned air introduced into the system, either directly into the air conditioning plant or indirectly, by building infiltration, may constitute a major portion of the total cooling load, particularly with high outdoor wet bulb temperatures. Similarly, winter heating and humidification loads may be significantly affected.

Ventilation rates are discussed in 2.3.2. Further information on this and on computation of infiltration loads is given in the CIBS Guide. Energy conservation requirements (see 2.6) should also be taken into account.

3.2.7 Arrangements of equipment/services. Central plant and distribution services should be arranged or located to achieve minimum cost in use. However, in practice, there are various reasons why some departure from the optimum arrangement may be necessary, such as:

- a) building size, configuration and aesthetics;
- b) diversity of application in the building;
- c) structural loading and space limitations;
- d) location of incoming utilities;
- e) location of fresh air and exhaust ducts having regard to recirculation or heat recovery;
- f) plant noise and vibration;
- g) accessibility for installation, maintenance and replacement.

Where heat recovery is to be employed, individual plant rooms adjacent to the space to be served may provide an economical and satisfactory solution. Self-contained air-conditioning units may be used instead of central plants but special care should be given to noise generation.

Cooling towers for cooling the condenser water are normally best located at roof level.

A duplicate fan and motor set are required in cases where ventilation is essential at all times e.g. internal lavatories, WC's, etc. In certain other cases, it may be necessary to provide standby motors and drives for fans etc.

In the case of an air-conditioning plant, complete duplication is not usually possible, owing to floor space and cost, but large areas of occupation should be served wherever practicable with distribution ductwork etc. from more than one air-conditioning plant so as to give some alleviation of conditions if any one plant fails. The total refrigerating load should be supplied by a multiple unit system arranged to take into account standby and part load requirements.

Consideration should be given to automatic changeover controls in such instances where internal conditions have to be maintained at all times particularly in unattended plant rooms.

Consideration should be given to both the appearance and function of inlet and outlet grilles, diffusers and louvres, exhaust fans, units, and air- and water-cooled condensers, to prevent nuisance to adjoining buildings and occupants. The location of external grilles and/or louvres, particularly those handling large volumes of air, can cause a nuisance with noise being emitted from the plant and the possible emission of offensive smells or "stale air" from exhaust outlets. External plant such as roof fan units, condensers and large ductwork may be considered a nuisance from appearance or noise and in the case of evaporative cooling towers from the carry-over of moisture.

3.2.8 Access and facilities. To enable the installation to provide satisfaction to owners and to provide comfort for the occupants, it is essential that the proper commissioning is carried out and that full facilities are provided for operation and maintenance.

To keep the plant operating at its optimum condition, regular preventive maintenance is essential.

Both these requirements necessitate adequate access to essential parts of the plant and, for maintenance, facilities for lifting and removal of plant items are required.

3.2.8.1 Commissioning. To allow the commissioning engineers to complete their task, sufficient access to the system should be given and towers or ladders should be made available for access to high points of the plant. Where the ductwork or plant is situated above false ceilings or is situated in builders' work ducts, there should be adequate access to dampers, valves and measuring points.

All air volume and pressure test points should be drilled and plugs fitted.

3.2.8.2 Operation/maintenance

3.2.8.2.1 Access. Access for carrying out maintenance and the possible replacement of plant should be accommodated in the design and installation of the systems. Any alterations or additions to the building or plant after completion of the original installation should allow for proper access to be available to carry out maintenance work.

In providing access for maintenance the following points should be considered.

- a) Doorways, corridors, passageways, etc., should be unrestricted to allow good access for operatives, tools and any replacement parts, or in some cases complete units, that may be required.
- b) All purpose-installed lifting beams or points in plant rooms or elsewhere should be free from obstruction.
- c) Floor areas in plant rooms or around major items of plant should be free from obstruction for the use of lifting equipment that may be required, such as temporary scaffolding, lifting legs, hydraulic mobile hoists and, in some cases, mobile cranes.
- d) Purpose-installed access trap-doors in floors should be readily accessible, and they should be able to be opened without being a safety hazard or should be provided with safety guards or rails.
- e) Sufficient access should be readily available around plant where regular and planned maintenance, cleaning and/or removal of parts of plant is to be carried out such as withdrawal of tube batteries and strainers, and the changing of filters and vee belt drives.
- f) Suitable access and storage should be provided for such items as replacement filters or filter media, drums of lubricating oil, bottles of refrigerant, etc.
- g) Access should be provided for plant, control equipment, balancing dampers, valves, test points, changeover dampers, etc. when installed in ceiling spaces, service voids, ducts or other confined spaces.

In buildings with systems installed in ceiling spaces, to eliminate the unnecessary dismantling of ceiling tiles or panels, it is advisable to use a form of coding on the tile or panel, e.g. coloured buttons, to indicate the location and type of equipment, such as damper, fire damper access panel in ductwork, motorized valve or damper, etc.

h) An access door or access facilities should be provided in ductwork sections, large fans, plenum chambers, air-handling units, for maintenance of parts within the plant.

3.2.8.2.2 Facilities. Proper welfare facilities and safety measures are required to be provided for all personnel carrying out work on installations. Details of such requirements under the various Acts of Parliament and Regulations are given in section two of this code.

It is advisable to have readily available safety notices, clearly indicating such information as electrical hazards, warning of maintenance work in progress, plant or section of plant being isolated, etc. Suitable locks or locking devices should be used to prevent unauthorized interference with electrical equipment, valves or plant.

Local isolation should always be available for electrical equipment under the direct control of the operative working on the plant.

It is advisable to provide proper workshop and storage facilities for tools and spares.

With larger types of installations, suitable accommodation should be provided with adequate facilities for keeping records, manuals, drawings and planned maintenance charts.

When 110 V supply is not available for electrical hand tools, it is essential to provide suitable portable transformers properly wired with trailing leads and plug connections.

(230/250) V supply should not be used for electrical hand tools except in the workshop where they should comply with the relevant regulations.

(230/250) : (400/415) V supply portable transformer type electrical welding machines should be properly wired with the necessary isolator and fuses.

Special tools or implements may be provided with some types of equipment and it is advisable to ensure the proper control in the use of these items with records of issue and return to the workshop or stores.

Adequate fixed lighting compatible with the location is advisable in major items of plant where regular maintenance is to be carried out such as in large air-handling plant, filter chambers, humidifiers, etc.

Trailing electrical leads should be made up from the proper materials with any associated lamp protected by a suitable shield or cage.

Suitable means for draining down and for possible quick filling of water systems should be available. The use of fire hose reels for such purposes should not be allowed, in order to prevent loss, misuse or damage to the fire fighting facilities.

3.3 System design

3.3.1 Ductwork and air distribution systems

3.3.1.1 Materials. Ductwork is normally manufactured, erected and finished to the specifications of the HVCA. Designers should specify whichever is appropriate for the velocity, pressure and materials to be employed.

Ductwork may be manufactured from metal, plastics, resin-bonded glass fibre, asbestos cement, etc. The most commonly used material is galvanized steel. Where building materials, such as concrete or brick, are used in the formation of airways, the interior surface should be fire resistant, smooth, airtight and not liable to erosion.

3.3.1.2 Design principles. There are two main categories of ductwork systems.

a) *Low velocity, low pressure.* In these systems duct velocity is less than 10 m/s, and static pressures are less than 0.5 kPa for the distribution system and 1 kPa for the plant connections.

b) *High velocity, high pressure.* In these systems duct velocity is within the range 10 m/s to 40 m/s; positive static pressures in the system are between 0.5 kPa and 2.5 kPa, and negative static pressures up to 0.5 kPa.

3.3.1.3 Ductwork design. Design calculations made to determine the size and configuration of ductwork in respect of pressure drop and noise generation should conform to methods and data given in the CIBS Guide. Considerations relating to energy conservation are dealt with in 2.6 of this code.

Ductwork design should also take note of the CIBS publication "Recommendations relating the design of air handling systems to fire and smoke control in buildings".

3.3.1.4 Layout considerations. When designing ductwork, consideration should be given to:

- a) coordination with building, architectural and structural requirements;
- b) coordination with other services;
- c) simplifying installation work;
- d) providing facilities and access for commissioning and testing;

e) providing facilities and access for operation and maintenance;

f) meeting fire and smoke control requirements;

g) ensuring that the various parts of the ductwork system are readily identified by colour coding or symbols as described in the current HVCA ductwork specification.

3.3.2 Piping and water distribution systems. This subclause gives general guidance on the design and layout of the piping system, but excludes steam, condensate, and high and medium temperature hot water services.

3.3.2.1 Materials. Both steel piping with welded or flanged joints and copper piping are used. The use of plastics pipes for cold water in place of steel is becoming increasingly common, as they offer ease of installation with cleanliness and corrosion resistance. It is important, however, when plastics pipes are used to take due account of the high coefficient of expansion and lower mechanical strength when designing piping supports, expansion joints and pipe anchors.

The choice of materials for any installation will be governed by economic considerations, but care should be taken to minimize the possibility of corrosion when choosing material combinations. The use of corrosion inhibitor is recommended (see 3.6).

3.3.2.2 Design principles. The system design should achieve the following two main objectives.

a) A good distribution of water to the various air coolers at all conditions of load.

This will be influenced by the method chosen to control the heat transfer capacity of the air coolers. Failure to achieve a good hydraulic design can lead to difficulties with system balancing to obtain acceptable control. Adequate provision should be made for measuring flow rates and pressure differentials.

b) An economic balance between pipe size and pumping cost.

Excessive water velocities should be avoided, as they can lead to noise at pipe junctions and bends.

When multiple water-chilling packages are to be used in a large system, the control of the machines and the arrangement of the water circulation should be considered as an integrated whole: it is not possible to obtain a satisfactory result by considering control and system design separately.

With larger systems and modulating control of machine capacity, there is normally no need to provide a buffer tank in the circuit. For smaller systems where refrigerating capacity is controlled in steps, a buffer tank is often useful to attenuate the temperature change caused by a capacity step and to minimize excessive cycling of the refrigerating compressor. Again, the choice should be made after consideration of all the factors involved.

Temperature changes in the system lead to changes in the volume of the water, which has to be allowed to expand into a suitable expansion tank. It is essential that the point at which the tank is connected into the system be such that it is never shut off. It is normal practice to locate the tank above the highest point in the system, so that a positive pressure is maintained when all the pumps are stopped; if this is not possible, a closed tank can be installed at a lower level and pressurized by an inert gas.

For air-conditioning systems, water is the usual heat transfer medium used to convey the heat from the air coolers to the primary refrigerant in the evaporator. In certain special cases, when temperatures lower than $\pm 5^\circ\text{C}$ are required, an anti-freeze such as ethylene glycol may be added to depress the freezing point.

3.3.2.3 Piping design. The arrangements of the water piping will depend on the heating or cooling systems chosen as being the most suitable for the building. These systems are described in the design handbooks prepared by the CIBS and by the ASHRAE.

The water velocities normally used are dependent on pipe size but are usually in the range 1 m/s to 3 m/s. Noise can be caused by velocities in excess of 4 m/s but this is more likely to be caused by air left in the pipes by inadequate venting. Where materials other than steel are used, erosion can occur at the higher velocities particularly if the water is allowed to become acidic.

The power expended in circulating the water around the system is proportional to the pressure loss and the flow. It is therefore an advantage to design the system with a maximum water temperature rise and hence a minimum flow rate.

Air-conditioning systems operate for a large part of the time at less than the design load, and this means that operating costs can be minimized if the water quantity circulated can be reduced at light load. This should be done without affecting the water distribution.

3.3.2.4 Layout considerations. The layout of the main pipe runs should be considered in relation to the building structure, which will have to support their weight and carry the imposed axial loads. The positioning of expansion joints should be considered in relation to the branches, which may only accommodate small movements, and the pumps, which should not be subjected to excessive loads from the piping.

Provision should be made for venting air and any gas formed by corrosion processes from the high points in the system: failure to do this can lead to restricted water flows and poor performance.

New systems invariably contain debris of one sort or another left during construction, and this can cause trouble by blocking pipes, control valves and pumps if it is not removed during commissioning. Piping systems should be designed to permit proper cleaning and flushing and should include suitable strainers at appropriate locations. Reference should be made to CIBS Commissioning Code W.

3.3.3 Thermal insulation. Ventilation, air-conditioning and water distribution systems, including components within such systems, may be carrying heated or chilled fluids. Thermal insulation is required to prevent undue heat gain or loss and also to prevent internal and external condensation; a vapour seal is essential if there is a possibility of condensation within the insulating material.

The selection of suitable thermal insulating materials requires that consideration be given to their physical characteristics as follows.

- a) Fire properties. Certain insulating materials are combustible or may, in a fire, produce appreciable quantities of smoke and noxious and toxic fumes.
- b) Materials and their finishes should inherently be proof against rotting, mould and fungal growth, and attack by vermin, and should be non-hygroscopic.
- c) Materials should not give rise to objectionable odour at the temperature at which they are to be used.
- d) The materials should not cause a known hazard to health during application, while in use, or on removal, either from particulate matter or from toxic fumes.
- e) A low thermal conductivity should obtain throughout the entire working temperature range.

Further detailed information on the properties, the selection and the use of thermal insulating and vapour sealing materials is contained in the following documents:

CP 3005

BS 3958

BS 5422

The Asbestos Regulations 1969

Health and Safety at Work etc. Act 1974

3.3.4 Refrigerant piping for vapour compression systems. This subclause considers refrigeration systems designed specifically for air-conditioning applications using the usual halocarbon refrigerants. A large proportion of the refrigeration systems are supplied in the form of packaged units, in which the piping and control systems are standardized.

While the design criteria mentioned here are applicable to the packaged units, they are intended to apply mainly to those systems that are custom built in the building and have relatively long pipe runs with major components on different levels. The design of these systems may need to be further complicated, by the need to control the air coolers to give humidity control, although it is not considered appropriate to deal with this subject in this subclause.

3.3.4.1 Materials. The refrigerants and the lubricating oil in the system are non-corrosive to all metals, with the exception of magnesium and of aluminium in certain circumstances. Aluminium alloys are widely used for compressor components. Contamination of the refrigerant with water can lead to decomposition of the refrigerant with the resulting formation of acid products. These can also be produced very rapidly in the burnout of an hermetic motor and need to be removed completely or corrosion will occur.

The refrigerants and the oil will affect many jointing materials, so that these should be carefully selected. Refrigerating plant manufacturers can advise on suitable types.

Refrigerant lines are generally of copper in the smaller sizes, and of steel for larger sizes. It is important that all foreign matter should be excluded from the refrigerant system. All tubing should be obtained and stored in a clean, dry condition with the ends sealed until required for use.

During fabrication every effort should be made to exclude dirt and moisture, pipe ends should always be kept closed and pipes should be cleaned out after bending.

All welding, brazing and soldering materials should be selected for use in refrigerating systems and the standard of workmanship in making the joints should be high. It is important that flux, welding scale and debris be cleaned away before the pipes are fitted. Soft soldered joints are not recommended except for the capillary type fittings that are available for copper pipes.

Flare and compression type connectors are used for copper and some drawn steel pipes; these are completely satisfactory provided the joints are correctly made in accordance with the manufacturer's instructions. It is important that pipes are adequately supported as excessive movement owing to vibration can lead to fatigue failure of the joints or of the base pipe material, in particular with copper.

3.3.4.2 Design principles. Refrigerant piping systems should be designed for minimum pressure drop since pressure losses decrease useful cooling capacity and increase compressor input energy. It is necessary for account to be taken of changes in the state of the refrigerant, which occur as it circulates, and of refrigerant miscibility with compressor lubricating oil. System design should comply with all relevant statutory requirements and with the requirements for refrigeration safety in BS 4434.

Refrigerant piping systems should be designed to:

- a) maintain a clean and dry system;
- b) ensure correct distribution of liquid refrigerant to evaporators;
- c) ensure that lubricating oil is always transported by the refrigerant flow back to the compressor and avoid accumulation and slug flow in the suction line;
- d) protect compressors by:
 - 1) preventing liquid refrigerant draining into or condensing in the compressor during shutdown;
 - 2) preventing liquid refrigerant from entering the compressor during operation;
 - 3) preventing excess suction gas superheat at compressor inlet.

3.3.4.3 Piping design. Refrigerant piping should be sized with due regard to pressure drop, the minimum gas velocities necessary for oil entrainment and return, and cost factors.

3.3.4.3.1 Liquid lines. The liquid line carries liquid refrigerant from the condenser to the expansion valve at the evaporator inlet.

Compressor lubricating oil is sufficiently miscible with refrigerant in the liquid phase to ensure that oil is always carried along with the refrigerant.