
Code of practice for
**Design of buildings : ventilation principles
and designing for natural ventilation**

(formerly CP 3 : Chapter 1 (C))

Code de bonne pratique pour la conception des bâtiments :
Principes de ventilation et études de ventilation naturelle

Richtlinie für Baukonstruktionen :
Belüftungsgrundsätze und Konstruktion für natürliche Belüftung

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Foreword

This code of practice is a revision of CP 3 : Chapter I(C): 1950 which it supersedes. It takes account of the research on ventilation which has taken place since the original code was first published.

The design of mechanical ventilation systems is dealt with in BS 5720.

This revision gives recommendations for the supply of outside air and also covers briefly the processes by which these recommendations may be put into practice.

Requirements regarding the ventilation of buildings are controlled by the following Building Regulations.

- (a) The Building Regulations 1976, applicable in England and Wales except London as covered by (b);
- (b) The London Building Acts (Amendment) Act 1939;
- (c) The Building Standards (Scotland) (Consolidation) Regulations, 1971;
- (d) The Building Regulations (NI) 1977;
- (e) The Code of Practice for Buildings of Excess Height and/or Additional Cubical Extent requiring

approval under Section 20 of the London Building Acts (Amendment) Act 1939, applicable to Inner London.

Where the expression 'comply with the relevant Building Regulations' is used, it means compliance with the above regulations or any revisions currently in force.

Further requirements relating to the ventilation of buildings are contained in the following regulations:

- (f) Offices, Shops and Railway Premises Act, 1963;
- (g) Factories Act, 1961;
- (h) Health and Safety at Work etc. Act, 1974.

Advisory documents covering ventilation practice are issued in the form of building notes by the Department of Health and Social Security and the Department of Education for those types of buildings for which they have responsibility. Advice is also given in the Greater London Council's Code of Practice for means of escape in case of fire.

Appendix F is a bibliography and references to publications listed in it are shown thus: reference [15].

British Standard Code of practice for

Design of buildings : ventilation principles and designing for natural ventilation

Section one. General

1. Scope

This British Standard code deals with ventilation of buildings for human occupation.

In section two, the main reasons for the provision of ventilation are outlined and, where possible, recommended quantitative air flow rates are given. It is shown that these form the basis for air supply recommendations for different types of buildings and rooms characterized by usage. The basis for the choice between natural and mechanical ventilation is given.

Section three gives guidance upon the design of natural ventilation systems.

The design of mechanical ventilation systems is dealt with in BS 5720.

2. References

The titles of the standards publications referred to in this code are listed on the inside back cover.

3. Definitions

For the purpose of this code the definitions given in BS 5643 apply; other terms are defined as follows.

3.1 absolute temperature. Temperature measured with respect to absolute zero.

3.2 discharge coefficient. A coefficient which relates the volume flow rate through an orifice to its area and the applied pressure difference.

3.3 equivalent area. The area of a sharp-edged orifice through which air would pass at the same volume flow rate, under an identical applied pressure difference, as the opening under consideration.

3.4 gust ratio. The ratio of the maximum gust lasting three seconds in one hour to the mean wind speed over the same period, measured at an effective height of 10 m.

3.5 input rating. The heat available for liberation by combustion within an appliance, based upon the gross calorific value of the fuel.

3.6 kerosene. A petroleum oil fuel suitable for appliances with small vaporizing and atomizing burners; classified as class C in BS 2869.

3.7 open-flued appliance. An appliance designed to be connected to an open flue system; its combustion air being drawn from the room or internal space within which it is installed.

3.8 premium grade kerosene. Kerosene suitable for flueless space heaters, complying with the requirements of the specification for class C1 petroleum oil fuels in BS 2869.

3.9 reference static pressure. The static pressure in the free wind, away from any interference with the flow.

3.10 static pressure. The pressure which would be recorded by a pressure gauge moving with the flow (i.e. static relative to the fluid).

3.11 threshold limit value-time weighted average (TLV-TWA). The time weighted average concentration for a normal working day, or 40 h working week, to which nearly all workers may be repeatedly exposed day after day without adverse effect.

3.12 threshold limit value-short term exposure limit (TLV-STEL). The maximum concentration to which workers can be exposed for a period of up to 15 min continuously without suffering from (a) intolerable irritation, (b) chronic or irreversible tissue change, or (c) narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially to reduce work efficiency, provided that no more than four excursions per day are permitted, with at least 60 min between exposure periods, and provided that the daily TLV-TWA is not also exceeded.

3.13 wake. The region of disturbed flow which persists some distance downstream of a building or similar structure exposed to the wind.

4. Necessity for ventilation

The provision of permanent and/or controllable draught-free ventilation is necessary for all buildings. Designers should take all factors into consideration in determining the ventilation rate necessary for a particular project.

5. Notation

For the purposes of this code the following notation applies. Commonly used abbreviations for units of measurement are not listed.

A	Equivalent area of an opening
A_1, A_2, A_3, A_4	Equivalent area of specific openings denoted in the text
A_b	
A_w	
a	Exponent relating wind speed to height
C_d	Discharge coefficient for an opening
C_p	Surface pressure coefficient
c	Concentration of contaminant in air by volume
c_e	Concentration of contaminant in outside air
c_o	Concentration of contaminant at time $t = 0$



c_E	Equilibrium value of contaminant concentration
g	Acceleration due to gravity
H_1	Vertical distance between the centres of two openings in a wall
H_2	Vertical distance between top and bottom edges of a rectangular opening in a wall
h	Vertical distance between ground and the eaves or parapet
J	Function relating ventilation rate through an open window to the angle of opening, ϕ
K	Factor relating wind speed to height
k	Window leakage factor
L	Length of a crack
l	Length of a building
M	Metabolic rate
n	Exponent relating flow rate through crack to applied pressure difference
p	Surface pressure
$\bar{p}$	Mean surface pressure
p_o	Static pressure in undisturbed wind
Q	Volume flow rate of air
q	Input volume flow rate of contaminant
R	Air change rate
t	time
U	Thermal transmittance
u	Wind speed
u_m	Wind speed at 10 m, exceeded for a given proportion of time
u_r	Reference wind speed
V	Room volume
w	Width of building
z	Height
α	Angle made by wind relative to building
Δ	Difference between two values of the same quantity, e.g. ΔC_p
ϵ	Area ratio
θ	Absolute temperature
θ_e	Absolute temperature of outside air
θ_i	Absolute temperature of inside air
$\bar{\theta}$	Average of inside and outside temperature
ρ	Air density
ϕ	Angle made by an open window with the plane containing the wall of a building

- (b) dilution and removal of odours, tobacco smoke, toxic and flammable gases and other contaminants;
- (c) control of internal humidity;
- (d) provision of air for fuel burning appliances;
- (e) control of thermal comfort;
- (f) clearance of smoke resulting from a fire.

In 6.2 to 6.7 the need for ventilation is explained and quantitative guidance given on how these needs should be met in general.

6.2 Composition of outside air. In ordinary engineering practice fresh air means air from outside. The usually accepted composition of dry air is 20.94 % O₂, 0.03 % CO₂, 79.03 % N₂ and inert gases. The CO₂ content can be less than 0.03 % in country areas, and higher in built-up areas where it is a product of respiration and fuel combustion, perhaps nearer 0.04 %. In addition, air contains particulate matter and consideration should be given to the need for filtering. It also contains water vapour such that in winter it is about 80 % to 95 % saturated on average in Britain and in summer 55 % to 75 %.

6.3 Human respiration. The body requires oxygen for the production of energy at a rate approximately proportional to metabolic rate. This in turn is proportional to body surface area and to activity level. Metabolic rates are listed in references* [1] and [2] for a wide range of activities.

As an indication of the required flow rates†, table 1 gives values for general activity levels for an adult male. The corresponding rate for adult females can be taken as 75 % of that for adult males for the same activity.

Expired air contains 4.4 % by volume or (V/V) of CO₂ and if, as is usually the case, it mixes within the space into which the fresh air for respiration is being introduced, a gradual increase in CO₂ level will result. The threshold limit value for CO₂ is 0.5 % by volume and the flow rates necessary to accomplish this are also given in table 1.

Table 1. Outside air requirements for respiration

Activity (adult male)	Metabolic rate, M	Requirements for respiration; O ₂ concentration of 16.3 % in expired air	Requirements to maintain room CO ₂ at 0.5 % assuming 0.04 % CO ₂ in fresh air*
	W	litres/s	litres/s
Seated quietly	100	0.1	0.8
Light work	160 to 320	0.2 to 0.3	1.3 to 2.6
Moderate work	320 to 480	0.3 to 0.5	2.6 to 3.9
Heavy work	480 to 650	0.5 to 0.7	0.3 to 0.5
Very heavy work	650 to 800	0.7 to 0.9	5.3 to 6.4

*The rate of production of CO₂ in terms of metabolic rate M is $40 \times 10^{-6} M$ litres/s where M is in watts.

6.4 Dilution and removal of contaminants

6.4.1 General. Provided that good mixing takes place within the ventilated space, the supply rate of outside air necessary to limit the concentration of contaminant should be determined using equation (7) in appendix A. In many

Section two. General principles of ventilation

6. Basic data

6.1 General. A supply of outside air is required for one or more of the following purposes:

- (a) human respiration;

*References are listed in appendix F.

†The required flow rate of air, Q , is related to the metabolic rate, M , by the following expression:
 $Q = 0.001M$ litres/s where M is the metabolic rate (in watts).

situations, in particular, industrial works, laboratories and commercial kitchens, contaminants should be extracted mechanically as near to the source as possible. Other methods of counteracting contaminants by masking or adsorption and absorption may be considered. It should be noted that when air passes from one space to another in a building, the ventilation rate for each room will depend upon the total requirement of all the interconnecting spaces (see example in appendix A).

6.4.2 Limiting concentration of contaminants. The threshold limit value (TLV) is the level of concentration used by the Health and Safety Executive to define maximum concentration levels of contaminants in the work place. Values for many substances have been listed (see references [3] and [4]). They apply to airborne concentrations, and fit and healthy people at work for a 7 h or 8 h day and a 40 h working week. The TLV can be modified to cover shorter and longer periods. The TLV normally quoted is a time weighted average (TLV-TWA), and for some contaminants short term exposure limit (TLV-STEL) concentrations are given (see reference [3]) for exposure periods of 15 min.

For exposure times longer than 40 h in a week it seems reasonable that limits should be lower than the TLV-TWA especially for the general population which includes old, young and unfit people. Very little information is available but in the review (see reference [5]) data for continuous exposure to carbon monoxide in submarines and spacecraft indicate maximum concentrations of one fifth of the TLV-TWA.

When two or more contaminants are present their effects should be considered together if they act on the same parts of the body (see references [3] and [4]).

6.4.3 Density difference. It should be noted that some gases and vapours differ considerably in density from air

and may form layers which will not mix readily with the outside air. This may give rise to regions of dangerously high concentration despite a theoretically sufficient ventilation rate (see reference [6]).

6.4.4 Odour. The odours which emanate from the human body may create a disagreeable environment. The degree of nuisance, based on subjective judgement, has been shown (see reference [7]) to depend both upon the outside air supply rate per person and the density of occupation of the space concerned. Figure 1 gives the air supply rate per person to reduce odour nuisance to a moderate level for sedentary adults, as a function of occupation density. The particular problem of the removal of lavatory odours is discussed in reference [8].

6.4.5 Tobacco smoke. Apart from carbon monoxide production the smoking of tobacco can produce an undesirable odour, particularly to non-smokers, and because of certain of its constituents, in particular acrolein, can produce irritation to the eyes and nasal passages. Research has shown that the removal of tobacco smoke odour requires higher air flow rates than for the removal of associated irritants, and use is made of the results of this research in the derivation of fresh air requirements for areas where smoking occurs.

Current knowledge (see reference [5]) indicates a considerable variation in recommended flow rates. In the absence of more definitive information, a value of 20 m^3 per cigarette smoked appears to be a reasonable compromise. To translate this into an air supply rate requires a knowledge of the number of smokers present and the rate of smoking. The average smoker consumes 1.3 cigarettes per hour: this requires a fresh air rate of $26 \text{ m}^3/\text{h}$ or 7 litres/s per smoker. An allowance can be made for the fact that only a proportion of the adult population smokes, when determining the design ventilation rate of spaces which are relatively heavily

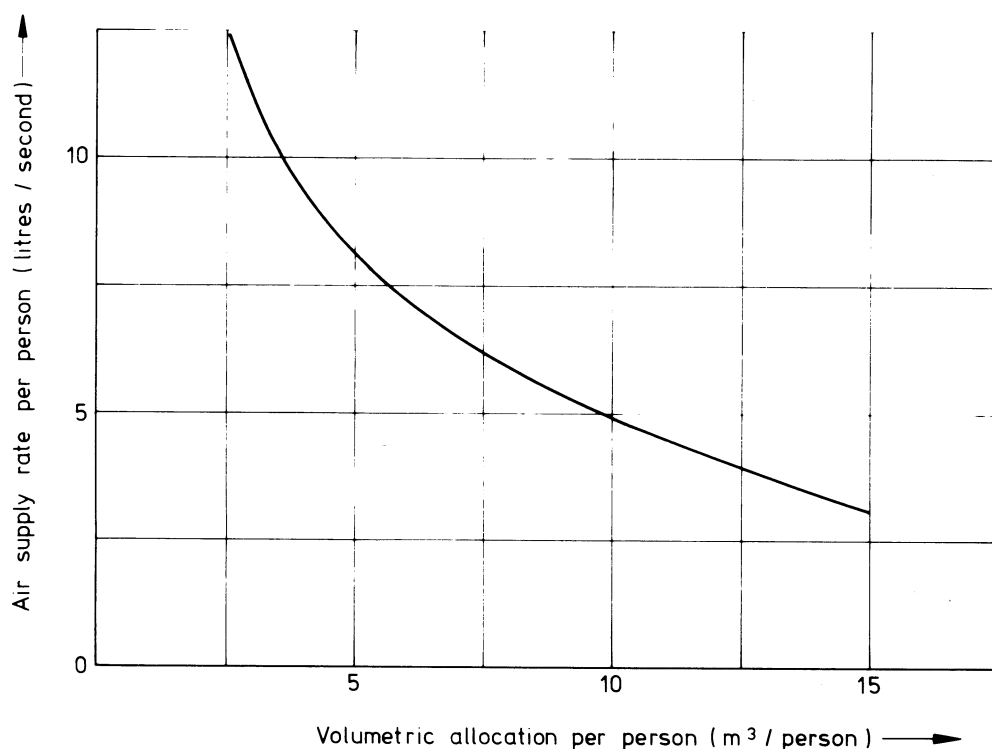


Figure 1. Air supply rate for odour removal

populated, e.g. open-plan offices, which may have a lower required flow rate per person than cellular offices (see reference [5]). It also follows that if the smoking rate is expected to be more than 1.3 cigarettes per smoker per hour, appropriate corrections will need to be made.

6.5 Control of internal humidity. The relative humidity (r.h.) of air is approximately equal to the ratio of the moisture content of the air to the moisture content of saturated air at the same temperature. Low relative humidities can give rise to respiratory discomfort and nuisance from electrostatic effects. High relative humidities incur the risk of condensation and mould growth on surfaces whose temperatures fall below the dewpoint temperature of the air. The reader should refer to BS 5250 which deals with factors affecting condensation and mould growth in dwellings, including the thermal properties of the structure, the temperature and humidity of the outside air and the heat and moisture input. The contribution made by ventilation is to lower the moisture content of the internal air by dilution with outside air which normally has a lower moisture content. For any required moisture level the flow rate will depend upon the moisture level in the outside air, and the rate of moisture input from such sources as respiration, cooking, washing and flueless combustion of certain fuels. Tables 2(a) and 2(b) give some guidance on the likely moisture input rates and, given the temperature and relative humidity of outside air, which for design purposes should be taken as 90 %, given flow rates should be obtained using equation (7) in appendix A. It should be noted that in newly constructed buildings large quantities of moisture are released from the fabric as the building dries out. Consideration should be given during this period to the question of whether additional ventilation should be provided (see reference [9]).

Table 2. Typical moisture emission rates

(a) Rates fixed by the nature of the process	Moisture emission rate
<i>Occupation</i> *:	
sleeping adult	0.04 kg/h
active adult	0.05 kg/h
<i>Flueless combustion</i> :	
natural gas	0.16 kg/h per kW
premium grade kerosene	0.10 kg/h per kW
liquefied petroleum gas	0.13 kg/h per kW
(b) Rates estimated*, but subject to variation due to occupants' lifestyle	
Cooking†	3.0 kg/day
Bathing, dishwashing, etc.	1.0 kg/day
Clothes washing	0.5 kg/day
Clothes drying†	5.0 kg/day

*From table 2 of BS 5250 : 1975

†From the process only and excluding fuel by-products.

For the particular case of steady state heat transfer, appendix B gives a simple method using a nomograph (see figure 2) for estimating the ventilation rates necessary to reduce the risk of surface condensation occurring.

6.6 Provision of air for fuel burning appliances

6.6.1 General provisions. An air supply to a fuel burning appliance is required for one or more of the following purposes:

- (a) to supply primary and secondary air for combustion;
- (b) to limit the concentration of combustion products within the space to an acceptable level (this is normally taken to be 0.5 % CO₂);
- (c) to prevent overheating of the appliance and its surroundings.

6.6.2 Primary and secondary air. The supply rate necessary to provide air for typical open-flued domestic fuel-burning appliances, both for combustion and for adequate operation of the flue, is about 0.8 litres/s to 1.1 litres/s per kW output of the appliance according to the appliance efficiency. (For gas appliances see BS 5440 : Part 2. For oil-burning appliances see BS 5410 : Parts 1 and 2.)

6.6.3 Control of concentration of combustion products. This applies to flueless combustion appliances where the products of combustion pass into the room or space containing the appliance. Flueless appliances are categorized as:

- (a) continuous, such as kerosene or gas space heaters;
- (b) intermittent, such as gas water heaters and cookers.

The criterion most usually applied in assessing the ventilation rate is the need to maintain the concentration of carbon dioxide below 0.5 %. For continuously operating appliances this leads to the specification of an air supply rate derived from equation (7) in appendix A and a knowledge of the constitution of the products of combustion. Table 3 shows the required flow rates for kerosene, liquefied petroleum gas and natural gas.

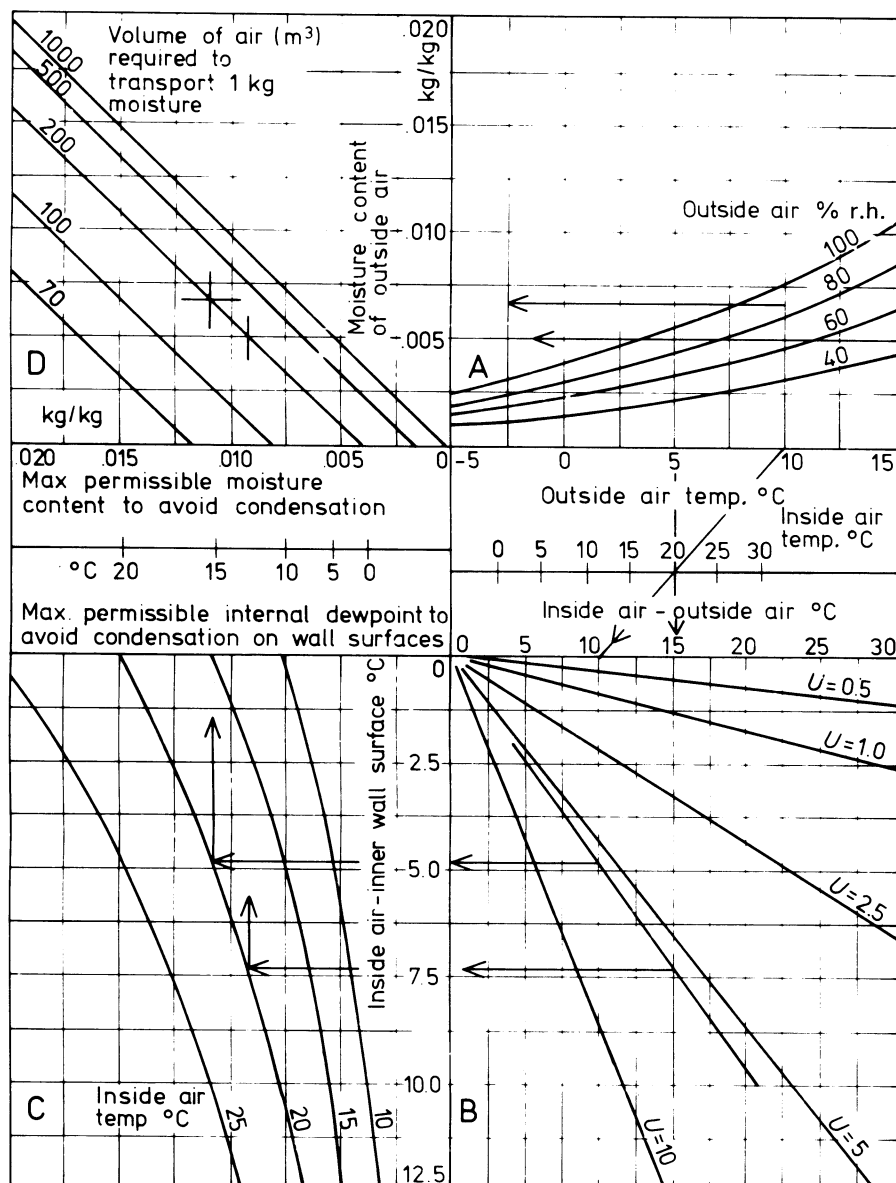
NOTE. For kerosene, another criterion should be applied, which is the need to maintain the concentration of sulphur dioxide below a recommended level. The value for air supply rate based on this criterion is also given for a fuel containing 0.06 % sulphur and with a limiting sulphur dioxide concentration of 5.0 p.p.m. (the TLV) and 1.0 p.p.m. (for continuous exposure of the general population).

For gas appliances which are likely to be operated intermittently for limited periods of time, a lower outside air supply rate is permissible since it is only necessary to ensure that the level of carbon dioxide concentration does not exceed 0.5 % during the period of operation of the appliance. Manufactured gas and natural gas produce 0.027 litres/s of carbon dioxide per kW heat input. Thus, equation (6) in appendix A should be used in order to determine the required ventilation rate, given the length of the period of operation of the appliance. It will be noted that room volume is required for this calculation. For a given heat output the ventilation requirement will increase with decreasing room volume.

NOTE. Direct fired air heaters are subject to special restrictions. Details can be obtained from the local gas authority.

6.6.4 Appliances in confined spaces. Consideration should be given to the provision of an air supply to heating appliances in confined spaces, to prevent overheating of such appliances and of their surrounding enclosures.

For further guidance reference should be made to BS 5410 : Parts 1 and 2, and to BS 5440 : Part 2 and references [10] and [11].



NOTE. The method of use of this nomograph is explained in appendix B. The two examples shown relate to appendix C.

Figure 2. Ventilation required to reduce the risk of surface condensation occurring on the inner wall surface for various wall U -values and ambient air conditions (Reproduced from reference [27] by permission of the Institution of Gas Engineers)

Table 3. Air supply rates required for flueless appliances

Fuel	Basis	Air supply rate
		litres/s per kW*
Natural gas	CO ₂ < 0.5 %	5.4
Liquefied petroleum gas	CO ₂ < 0.5 %	6.6
Premium grade kerosene	CO ₂ < 0.5 %	6.8
Premium grade kerosene	SO ₂ < 5.0 p.p.m.	1.8 †
Premium grade kerosene	SO ₂ < 1.0 p.p.m.	9.0 †

*Input rating of the appliance.

†These figures are based upon the maximum level of sulphur, of 0.06 % allowed by BS 2869. In many cases sulphur levels will be lower than this, in which case the required air supply rates may be reduced in proportion, e.g. for 0.04 % the rates would be 1.2 litres/s per kW and 6.0 litres/s per kW respectively.

6.7 Control of thermal comfort. Temperatures achieved in buildings depend upon the solar heat gain, the heat deliberately supplied, the heat generated by the occupants or processes within the building, the type of construction and the ventilation rate. Methods exist for relating the ventilation rates and corresponding temperatures.

6.8 Clearance of smoke resulting from an accidental fire.

A fire can generate large quantities of combustion products, namely hot gases carrying smoke particles and containing toxic or noxious and irritant products (usually referred to as 'smoke').

In the event of a fire within a building, ventilation by natural or mechanical means can be used to limit the spread of these products which could otherwise hinder or prevent escape and thus endanger the lives of the occupants, and restrict or prevent effective rescue and fire fighting by the fire brigade.

For certain kinds of building, provision should be made for:

- (a) the removal of smoke from escape routes;
- (b) the control of the spread of smoke and the removal of smoke and heat.

Requirements regarding fire ventilation can arise from statutory regulations, codes of practice, government circulars, conditions of licence, insurance, and fire brigade advice.

Fire ventilation may be required to operate either immediately (i.e. provision for permanent openings or openings automatically operated upon the actuation of a heat or smoke sensitive device) or be available for operation as and when required by the fire brigade (e.g. breakable pavement lights or manually operated openings).

The requirements for ventilation in the event of fire may, on occasion, be incompatible with those for normal ventilation. In most cases, larger flows of air or gases have to be allowed for, in directions sometimes different from those required for normal ventilation.

Refer to CP 3 : Chapter IV (currently being revised as Parts of BS 5588) and references [12], [13] and [14]

for specific recommendations concerning fire ventilation requirements and practice.

7. Application

7.1 General. Clause 6 sets out basic data in relation to the main reasons for providing a supply of outside air. In order to determine the required air supply rate for a specific building, or room within a building, these data should be combined with a knowledge of the use to which the building is to be put. Table 4, taken from reference [15], lists recommended outside air supply rates for a range of building types, based broadly upon the information given in clause 6, and these may be used for making initial assessments in the design process. Where possible, when more detailed information is available, the designer should calculate outside air requirements on a room by room basis in order to obtain a more efficient design. Examples are given in appendix C, in tabular form, for a domestic living room, and in figure 3, in graphical form, for an office. In general, the largest rate calculated for the purposes set out in

Table 4. Recommended outdoor air supply rates for air-conditioned spaces

(Reproduced from reference [15] by permission of the Chartered Institution of Building Services)

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

*See statutory requirements and local bye-laws.

†Rate of extraction may be overriding factor.

‡Where queueing occurs in the space, the seating capacity may not be the appropriate total occupancy.

NOTE 1. For hospital wards and operating theatres see Department of Health and Social Security Building Notes.

NOTE 2. The outdoor air supply rates given take account of the likely density of occupation and the type and amount of smoking.