BRITISH STANDARD

BS 5925:1991

Incorporating Amendment No. 1

Code of practice for

Ventilation principles and designing for natural ventilation

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee (BDB/-) to Technical Committee BDB/2, upon which the following bodies were represented:

Aggregate Concrete Block Association
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Timber Research and Development Association
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The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Association of Lightweight Aggregate Manufacturers
British Coal Corporation
British Concrete Masonry Association
Flat Roofing Contractors Advisory Board
Institution of Mechanical Engineers
Medical Research Council
National Council of Building Material Producers
Phenolic Foam Manufacturers' Association

This British Standard, having been prepared under the direction of the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 31 May 1991

First published September 1980
Second edition May 1991

The following BSI references relate to the work on this standard:
Committee reference BDB/2
Draft for comment 89/17211 DC

ISBN 0 580 19285 7

Amendments issued since publication

Amd. No.	Date	Comments
8930	December 1995	Indicated by a sideline in the margin

Contents

Foreword

This British Standard has been prepared under the direction of the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee. It supersedes BS 5925:1980, which is withdrawn.

This revision takes into account research on ventilation and indoor air quality that has taken place since the publication of BS 5925:1980. In particular, under section 2, the ventilation requirements for the dilution and removal of airborne pollutants have been updated and account taken of the guidance given in BS 5250. Under section 3, a new clause dealing with air infiltration has been introduced.

Recent increased awareness of the need for efficient use of energy in the design and management of buildings, as recommended in BS 8207, has led to greater insulation levels and reduced ventilation rates in both new and existing buildings. However, it is essential that a balance is struck between the needs for low ventilation rates commensurate with saving energy and the needs for higher ventilation rates required to ensure good indoor air quality and to reduce the risk of mould growth. Ventilation rates in different parts of a building may differ, depending on both the levels of occupancy and the occupant's activities in those parts. It is important to remember the complex interrelationship of factors affecting condensation and to take particular care when designing new buildings or considering changes or attempting to remedy problems in existing buildings.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 40, 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.

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Section 1. General

1 Scope

This British Standard gives recommendations on the principles which should be observed when designing for the natural ventilation of buildings for human occupation. The standard is in three sections, as follows:

Section 1. General

Section 2 outlines the main reasons for the provision of ventilation and, where possible, recommends quantitative air flow rates. 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. The design of mechanical ventilation systems is dealt with in BS 5720.

Section 3 gives recommendations on the design of natural ventilation systems and on the estimation of air infiltration rates in housing.

Appendix A is a bibliography and reference to publications listed in it are shown as:
(see Appendix A [15]).

Appendix B gives recommendations on evaluating contamination risks.

Appendix C gives recommendations on calculating ventilation rates to reduce the risk of surface condensation under steady state conditions.

Appendix D gives recommendations on determining ventilation requirements.

Appendix E gives recommendations on calculating reference wind speed.

Appendix F gives recommendations on calculating natural ventilation rates for a simple building.

This standard does not attempt to address thermal comfort aspects of ventilation such as indoor air movement, temperature stratification, exact position of ventilation openings etc.

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

2 Definitions

For the purposes of this British Standard the definitions given in BS 5643 and BS 6100 apply, together with the following.

2.1
absolute temperature

temperature measured with respect to absolute zero

2.2
discharge coefficient

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

2.3
equivalent area

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

2.4
input rating

heat available for liberation by combustion within an appliance, based upon the gross calorific value of the fuel

2.5
kerosine

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

2.6
open-flued appliance

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

2.7
premium grade kerosine

kerosine suitable for flueless space heaters, complying with the requirements of the specification for class C1 petroleum oil fuels in BS 2869

NOTE The non-preferred term is paraffin.

2.8
reference static pressure

static pressure in the free wind, away from any interference with the flow

2.9
static pressure

pressure which would be recorded by a pressure gauge moving with the flow, i.e. static relative to the fluid

2.10
wake

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

3 Symbols

For the purposes of this British Standard 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 A_b A_w	Equivalent area of specific openings denoted in the text
a	Exponent relating wind speed to height
C_d	Discharge coefficient for an opening
C_p	Surface pressure coefficient
$C_{\bar{p}}$	Mean 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_b	Volume flow rate of air due to the effect of temperature only
Q_w	Volume flow rate of air due to the effect of wind only
Q^r	Reduced air flow rate for intermittent contaminant emission
q	Input volume flow rate of contaminant
R	Ventilation rate
r	Return period of an intermittent pollutant source
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. $\Delta C_{\bar{p}}$
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 air temperatures
ρ	Air density
ϕ	Angle made by an open window with the plane containing the wall of a building.

Section 2. General principles of ventilation

4 Basic data

4.1 General

A supply of fresh air is required for one or more of the following:

a) provision for human respiration;

b) dilution and removal of airborne pollutants, including odours and tobacco smoke;

c) control of humidity;

d) provision of air for fuel-burning appliances;

e) control of thermal comfort;

f) clearance of smoke resulting from an accidental fire.

In **4.3** to **4.8** each of these is discussed and guidance given on quantitative requirements.

4.2 Composition of outside air

In ordinary engineering practice fresh air means air from outside. The usually accepted composition of dry air by volume is:

oxygen	20.94 %
nitrogen	79.03 %
carbon dioxide	0.035 %
inert gases	traces

The carbon dioxide content is variable and may be lower than 0.035 % in country areas and higher in built-up areas, due primarily to fuel combustion for transport, heating and industrial purposes. Outside air may also contain particulate matter and other combustion products such as sulphur dioxide and nitrogen oxides. These are currently limited by European Council Directives (see Appendix A [1]).

The main variable constituent of outside air is water vapour. In the UK this ranges from approximately 2 g/kg to 12 g/kg dry air over the year, with typical ranges of relative humidity, in winter of 80 % to 95 % and in summer of 55 % to 75 %.

4.3 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 Appendix A (2) and Appendix A (3) for a wide range of activities.

Expired air contains about 16 % oxygen and 4 % carbon dioxide and is fully saturated with water vapour. Human beings, in good health, can adapt to a range of oxygen concentrations with a minimum concentration, at typical ambient pressures, of approximately 12 %. The main limiting factor is, in practice, the build-up of carbon dioxide. Although higher levels of carbon dioxide can be tolerated with no serious health effects, a useful guide is the occupational exposure limit (see Appendix A [4]) of 0.5 %. Air flow rates necessary to accomplish this and a lower concentration of 0.25 % carbon dioxide are given in Table 1 for a range of activity levels.

4.4 Dilution and removal of airborne pollutants

4.4.1 *General*

A wide range of airborne pollutants is generated by sources within buildings. These pollutants may include gases, vapours, biologically inert particulates, such as dusts and fibres, and viable particulates, such as fungal spores, viruses, and bacteria. Such pollutants may have the potential to harm the health or comfort of occupants or may lead to damage to the building fabric.

Table 1 — Fresh air requirement values for respiration

Activity (adult male)	**Metabolic rate (*M*)**	**Flow rate to maintain room CO_2 at given level assuming 0.04 % CO_2 in fresh air**	
		0.5 % CO_2	**0.25 % CO_2**
	W	L/s	L/s
Seated quietly	100	0.8	1.8
Light work	160 to 320	1.3 to 2.6	2.8 to 5.6
Moderate work	320 to 480	2.6 to 3.9	5.6 to 8.4
Heavy work	480 to 650	3.9 to 5.3	8.4 to 11.4
Very heavy work	650 to 800	5.3 to 6.4	11.4 to 14.0

NOTE These values are based upon a production rate of carbon dioxide of 0.00004*M* L/s per person, where *M* is the metabolic rate in watts.

The Health and Safety Executive sets limiting concentrations for airborne pollutants in the form of occupational exposure limits (see Appendix A [4]). These, however, apply to occupational situations and are primarily concerned with healthy adult workers. They cannot, therefore, necessarily be applied to buildings in which the occupants may include other groups, such as children, the elderly or those in poor health. At present, there is no consistent approach to setting acceptable indoor concentrations of pollutants in such circumstances.

The factors which determine the concentration of an indoor air pollutant are set out and discussed in Appendix B. These lead to the following methods of control:

a) source removal;

b) source control;

c) extract ventilation close to source;

d) removal from air by filtration etc.;

e) dilution ventilation.

Choice of method of control depends upon a number of factors, including the nature of the pollutant and its sources, capital and running costs and practicability. Ventilation will affect the concentration of any pollutant and is the most appropriate means of control where both the production rate and the limiting concentration of pollutant are well defined and where no other method can be as readily used. In practice production rates are best known where the source is combustion or where the pollutant results from the presence or activities of occupants. Production rates are less well defined where the source is related to the fabric or furnishings of the building.

4.4.2 *Odour*

The human olfactory system is sensitive to a wide range of airborne substances. The characteristics of odour, such as intensity and quality, and its acceptability, cannot be measured directly by instrumentation and have to be assessed by psycho-physical methods using human judgement.

Occupants of buildings are rarely exposed to individual odorants but to complex mixtures, characterized by their source, the most common being body odour, tobacco odour, cooking odours and toilet odour. Control of body odour has formed the basis of standards for fresh air supply in many types of buildings for many years. Based upon the most recent research (see Appendix A [5, 6 and 7]) the minimum requirement to restrict annoyance to persons entering the space from outside is 8 L/s per person, where the occupants are sedentary.

4.4.3 *Tobacco smoke*

Tobacco smoke consists of "main-stream" smoke, inhaled by the smoker, and the remainder which is termed "side-stream" smoke. Environmental tobacco smoke consists primarily of the latter, augmented by the proportion of main-stream smoke which is exhaled by the smoker. It is a complex mixture of particles, gases and organic vapours, varying with the type of tobacco and mode of smoking.

The possible effects of exposure to environmental tobacco smoke include:

a) odour annoyance;

b) irritation of the mucous membranes in the respiratory tract and especially the eyes;

c) increased susceptibility to respiratory infection and reduced lung function;

d) toxic reaction to certain components; and

e) increased risk of lung cancer.

The dominant criteria when assessing the required control of tobacco smoke are odour (based upon the response of non-smokers entering a space in which smoking may occur) and the level of respirable, suspended particulates (based upon standards set for particulates in the ambient air [see **4.2**)]. These criteria indicate that the dilution air requirement is 120 m^3 per cigarette smoked. A lower air supply rate, 30 m^3 to 60 m^3 per cigarette smoked, should obviate mucous membrane irritation.

Rate of smoking varies with individuals and circumstances but as a guide the average rate of smoking is approximately 1.3 cigarettes per h per smoker. This figure, together with an estimate that approximately one-third of the adult population are regular smokers, yields on the basis of odour considerations a value varying between approximately 15 L/s per person in a large space in which the proportion of smokers is typical of the population at large to 40 L/s per person in a space in which all occupants are assumed to be smokers.

Table 2 — Moisture generation rates

(a) Typical moisture generation rates for household activities	
Household activity	**Moisture generation rate**
People:	
Asleep	40 g/h per person
Active	55 g/h per person
Cooking:	
Electricity	2 000 g/day
Gas	3 000 g/day
Dishwashing	400 g/day
Bathing/Washing	200 g/day per person
Washing clothes	500 g/day
Drying clothes indoor (e.g. using unvented tumble drier)	1 500 g/day per person

(b) Typical moisture generation rates from heating fuels	
Heating fuel	**Moisture generation rate**
	g/h per kW
[a]Natural gas	150
[a]Manufactured gas	100
Kerosine	100
Liquefied petroleum gas	130
[a]Coke	30
[a]Anthracite	10

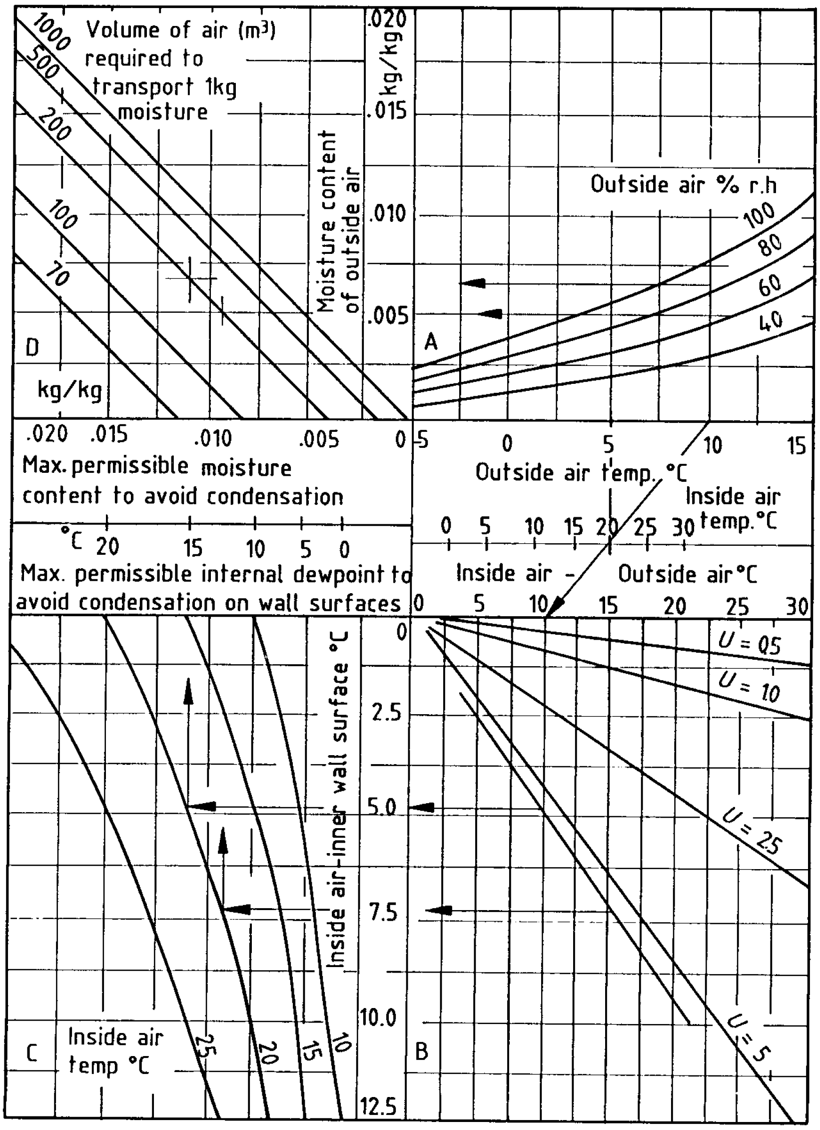
(c) Daily moisture generation rates for households			
Number of persons in household	**Moisture generation rates**		
	[b]Dry occupancy	**[c]Moist occupancy**	**[d]Wet occupancy**
	kg/day	kg/day	kg/day
1	3.5	6	9
2	4	8	11
3	4	9	12
4	5	10	14
5	6	11	15
6	7	12	16

[a] Most heating appliances using these fuels are ventilated to the outside air. consequently the water vapour produced by combustion is not released directly into the dwelling.

[b] Dry occupancy, i.e. where there is proper use of ventilation; includes households unoccupied during the day; results in an internal vapour pressure up to 0.3 kPa in excess of the external vapour pressure.

[c] Moist occupancy, i.e. where internal humidities are above normal; likely to have poor ventilation; possibly a family with children; water vapour excess is between 0.3 kPa and 0.6 kPa.

[d] Wet occupancy, i.e. ventilation hardly ever used; high moisture generation; probably a family with young children; water vapour pressure excess is greater than 0.6 kPa.



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

Figure 1 — 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 [9] by permission of the Institution of Gas Engineers)

4.5 Control of internal humidity

The relative humidity of air is 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 that have temperatures that fall below the dewpoint temperature of the air. Reference should be made 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. Table 2(a), Table 2(b) and Table 2(c) 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 95 %, required flow rates should be obtained using equation 9 in Appendix B. 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 drying-out period to the question of whether additional ventilation should be provided (see Appendix A [8]).

For the particular case of steady state heat transfer, Appendix C gives a simple method using a nomograph (see Appendix A [9] and Figure 1) for estimating the ventilation rates necessary to reduce the risk of surface condensation occurring. BS 5250 deals in more detail with the ventilation rates required to avoid surface condensation.

4.6 Provision of air for fuel-burning appliances

4.6.1 *General provisions*

An air supply to a fuel-burning appliance is required for one or more of the following purposes:

a) to supply air for combustion and correct flue operation;

b) to limit the concentration of combustion products within the spaces to an acceptable level (this is normally taken to be 0.5 % CO_2);

c) to prevent overheating of the appliance(s) and its surroundings.

4.6.2 *Air supply*

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 in the range of 0.4 L/s to 30 L/s per kW output of the appliance according to the appliance efficiency. (For gas appliances see BS 5440-2. For oil-burning appliances see BS 5410-1 and BS 5410-2. For solid-fuel-burning appliances see BS 8303.)

NOTE 1 Modern gas-burning condensing boilers typically require around 0.4 L/s per kW output whilst gas-burning decorative fuel effect appliances may require up to about 30 L/s per kW output. Other appliances with open flues tend to have air supply requirements in the range 0.8 L/s to 3.5 L/s per kW output.

NOTE 2 The air supply required for appliances burning solid fuel is usually in the range given in **4.6.2**. However, the requirement is more commonly specified in terms of the free area of a ventilator in the room or space containing the appliance. A solid-fuel-burning open appliance requires an air entry opening with a free area of at least 50 % of the appliance throat-opening area as defined in BS 8303. Other solid-fuel appliances require an air entry opening with a total free area of at least 550 mm^2 per kW of rated output above 5 kW. Where a draught stabilizer is used the total free area should be 300 mm^2 for each kW of rated output.

4.6.3 *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 kerosine or gas space heaters;

b) intermittent, such as gas water heaters and cookers.

The criterion most usually applied in assessing their ventilation rate is the need to maintain the concentration of carbon dioxide below 0.5 %. For continuously operating appliances this leads to the specifying of an air supply rate derived from equation (9) in Appendix B and a knowledge of the production rate of carbon dioxide. Table 3 shows the rates of production of carbon dioxide and the derived air flow rates for kerosine, liquefied petroleum gas and natural gas.

Table 3 — Flueless appliances: carbon dioxide production rates and air supply rates

(a) Carbon dioxide production rates

Fuel	**CO_2 production rate**
	L/s per kW
Natural gas	0.027
Manufactured gas	0.027
Liquefied petroleum gas	0.033
Kerosine	0.034
Solid fuel	0.048

(b) Air supply rates

Fuel	**Air supply rate**	**Basis**
	L/s per kW	
Natural gas	5.4	$CO_2 < 0.5$ % (*V*/*V*)
Manufactured gas	5.4	$CO_2 < 0.5$ % (*V*/*V*)
Liquefied petroleum gas	6.6	$CO_2 < 0.5$ % (*V*/*V*)
Premium grade kerosine	6.8	$CO_2 < 0.5$ % (*V*/*V*)
Premium grade kerosine	1.2	$SO_2 < 5.0$ Vppm
Premium grade kerosine	6.0	$S0_2 < 1.0$ Vppm

NOTE 1 For kerosine, 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 premium grade kerosine (class C1) containing 0.04 % sulphur and with a limiting sulphur dioxide concentration of 5.0 Vppm (the short-term exposure limit) and 1.0 Vppm (for continuous exposure of the general population). There is a standard grade kerosine available (class C2), with sulphur content up to 0.2 %, which should not be burned in flueless domestic heating appliances.

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 L/s of carbon dioxide per kW heat input. Thus, equation (7) in Appendix B should be used in order to determine the 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 2 Direct-fired air heaters are covered in BS 6230.

4.6.4 *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.

NOTE For further guidance reference should be made to BS 5410-1 and BS 5410-2, BS 5440-2 and to Appendix A (10).

4.7 Control of thermal comfort

For detailed discussion of the factors which determine the thermal comfort of occupants reference should be made to the CIBSE Guide (see Appendix A [11]). Thermal comfort is also discussed in reference Appendix A (12). Indoor temperature is a prime determinant of comfort and this depends upon a number of factors including the use of heating (or cooling) plant, adventitious thermal gains, the thermal characteristics of the building and the ventilation rate. A range of methods, largely computer-based, is available (see Appendix A [13]) which allow ventilation rate to be related to comfort for any particular building and conditions. A simplified approach is given in CIBSE Guide (see Appendix A [14]).

4.8 Removal 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 general removal of smoke and heat.

Requirements regarding fire ventilation can arise from statutory regulations, government circulars, conditions of licence, insurance, etc.

Fire ventilation may be required to operate either immediately (i.e. 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.

NOTE Refer to BS 5588 and Appendix A (15) for specific recommendations concerning fire ventilation requirements and practice.

5 Application

5.1 General

Clause **4** 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 or room is to be put. Table 4(a) taken from the CIBSE Guide, Volume A 1986, Section A1, lists recommended outdoor air supply rates for a range of building types and these may be used in the initial design process. Table 4(b) taken from the CIBSE Guide, Volume B 1986, Section B2, has somewhat greater outdoor air supply rates for sedentary occupants, based on recent research which reflects changes in occupants' tolerances of tobacco smoke. Where possible, the designer should calculate outside air requirements on a room-by-room basis in order to obtain a more efficient design. An example is given in Appendix D for a domestic living room. In general, the largest rate calculated for the purposes set out in clause **4** defines the required air supply rate. In all cases, however, any calculated rates are subject to the overriding need to satisfy statutory or similar regulations.

It was noted in **4.4.1** that many pollutants may be better controlled by methods other than ventilation, in particular by restricting source emission. However, in setting standards for this form of control a basic level of ventilation may be assumed and, for this reason, even unoccupied spaces require some degree of ventilation although this is generally lower than that required when they are in normal use.

5.2 Special applications

The provision of ventilation is required in some types of buildings for special applications, examples of which include:

a) in factories and industrial processes, to remove hot air, toxic and unpleasant contaminants, smoke and products of combustion in the event of a fire;

b) in garages or enclosed car parks and vehicle tunnels, to remove exhaust gases (particularly carbon monoxide), petrol vapour and smoke in the event of a fire;

c) in hospitals, to control cross-infection in special care units and to reduce the level of airborne bacteria in operating theatres;

d) in large commercial kitchens, to remove excess heat, steam and cooking odours;

e) in underground rooms and floor areas above ground not provided with normally openable windows, to remove smoke in the event of a fire;

f) in internal common access lobbies and corridors in blocks of flats and maisonettes, to remove smoke resulting from a fire.

NOTE See Appendix A (16) for specific requirements.

6 Provision for ventilation

6.1 General considerations

6.1.1 *Methods of ventilation*

In order to supply the air flow rates referred to in clause **5**, either natural or mechanical ventilation systems can be employed. This clause describes briefly the main characteristics of each system. Factors affecting the choice of system are set out in clause **7**.

Section 3 deals in detail with the design of natural ventilation systems, while the general design, planning and installation of mechanical systems is covered by BS 5720 and Appendix A (17) and (18).

Table 4 — Recommended outdoor air supply rates

(a) Recommended outdoor air supply rates for a range of building types (From reference [11])

Type of space	Smoking	Outdoor air supply		
		Recommended	Minimum (the greater of the two values should be taken)	
		Per person	Per person	Per m^2 floor area
		L/s	L/s	L/s
Factories[ab]	None	8	5	0.8
Offices (open plan)	Some			1.3
Shops, department stores and supermarkets	Some			3.0
Theatres[a]	Some			—
Dance halls[a]	Some	12	8	—
Hotel bedrooms[b]	Heavy			1.7
Laboratories[b]	Some			—
Offices (private)	Heavy			1.3
Residences (average)	Heavy			—
Restaurants (cafeteria)[bc]	Some			—
Cocktail bars	Heavy	18	12	—
Conference rooms (average)	Some			—
Residences (luxury)	Heavy			—
Restaurants (dining rooms)[b]	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
Kitchen (domestic)[b]				10.0
Kitchen (restaurant)[b]				20.0
Toilets[a]				10.0

(b) Recommended outdoor air supply rates for sedentary occupants (From reference [16])

Condition	Recommended outdoor air supply rate
	L/s per person
With no smoking	8
With some smoking	16
With heavy smoking	24
With very heavy smoking	32

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.

[a] See statutory requirements and local bye-laws.

[b] Rate of extraction may be overriding factor.

[c] Where queuing occurs in the space, the seating capacity may not be the appropriate occupancy.

6.1.2 *Infiltration*

The uncontrolled exchange of air through adventitious openings in the envelope of a building, such as cracks around windows or at the junction of building components, is termed air infiltration. It is present to varying degrees in nearly all buildings, including those that are mechanically ventilated, unless special attention has been paid to the design and to quality control during building to ensure an airtight structure. Infiltration contributes to the total ventilation rate, but because it is uncontrolled its usefulness can be limited. The general physical processes governing infiltration are the same as those governing natural ventilation, set out in section 3, except that the characteristics of the flow paths are not well defined.

A method of measuring air leakage in order to estimate infiltration performance, applicable to housing, is set out in clause **15**.

6.1.3 *Inlets and outlets*

Regardless of the method employed for ventilation, the supply of fresh air to a space should be complemented by provision for the removal of an equal quantity of air from the space. In general, air inlets and outlets are separate, although significant air exchange can occur through a single large opening under certain conditions (see **13.2**). Figure 2 shows typical possibilities for inlets and outlets, for both natural and mechanical ventilation systems.

6.1.4 *Natural ventilation*

Natural ventilation is the movement of air through openings in the building fabric, due to wind or to static pressures created by differences in temperature between the interior and exterior of the building (generally known as “stack” effect), or to a combination of these acting together. The mechanisms of natural ventilation are described in detail in section 3, but it should be noted here that natural ventilation is subject to the variability of wind speed, wind direction and air temperature. Not only do these affect the rate of fresh air supply, but they also determine whether any opening will act as an inlet or outlet for the air in any space within the building.

6.1.5 *Mechanical ventilation*

There are several methods of mechanical ventilation, the simplest being the supply or extraction of air from a space using a fan. In these cases an adequate opening should be supplied to allow the exit or entry of air, in order that the fan can operate satisfactorily. More complex systems involve the use of ducted air supply from centrally located fans, possibly providing supply and extraction of air, conditioning of the air and heat recovery from the extracted air.

The main advantage of mechanical ventilation is its controllability. In principle a mechanical system can be designed to satisfy the air requirements of any space within specified limits. In practice, constraints on its use are cost and space limitations.

6.1.6 *Effects of ventilation*

The main effect is the satisfaction of the recommendations set out in clause **5**, by providing outside air for dilution or to make up for the extraction of any contaminant at its source. The introduction of air from outside a space can affect the movement of air within the space. These aspects are discussed more fully in **6.2** and **6.3**. In addition, it should be noted that the introduction of outside air imposes an energy load, and this should be taken into account in the overall design of the building and its services.

6.2 Air supply

6.2.1 *General*

The purposes of ventilation are to ensure correct operation of combustion appliances, and to dilute airborne pollutants. In calculating the required flow rates for pollutant dilution it is assumed that:

a) steady state conditions apply; and

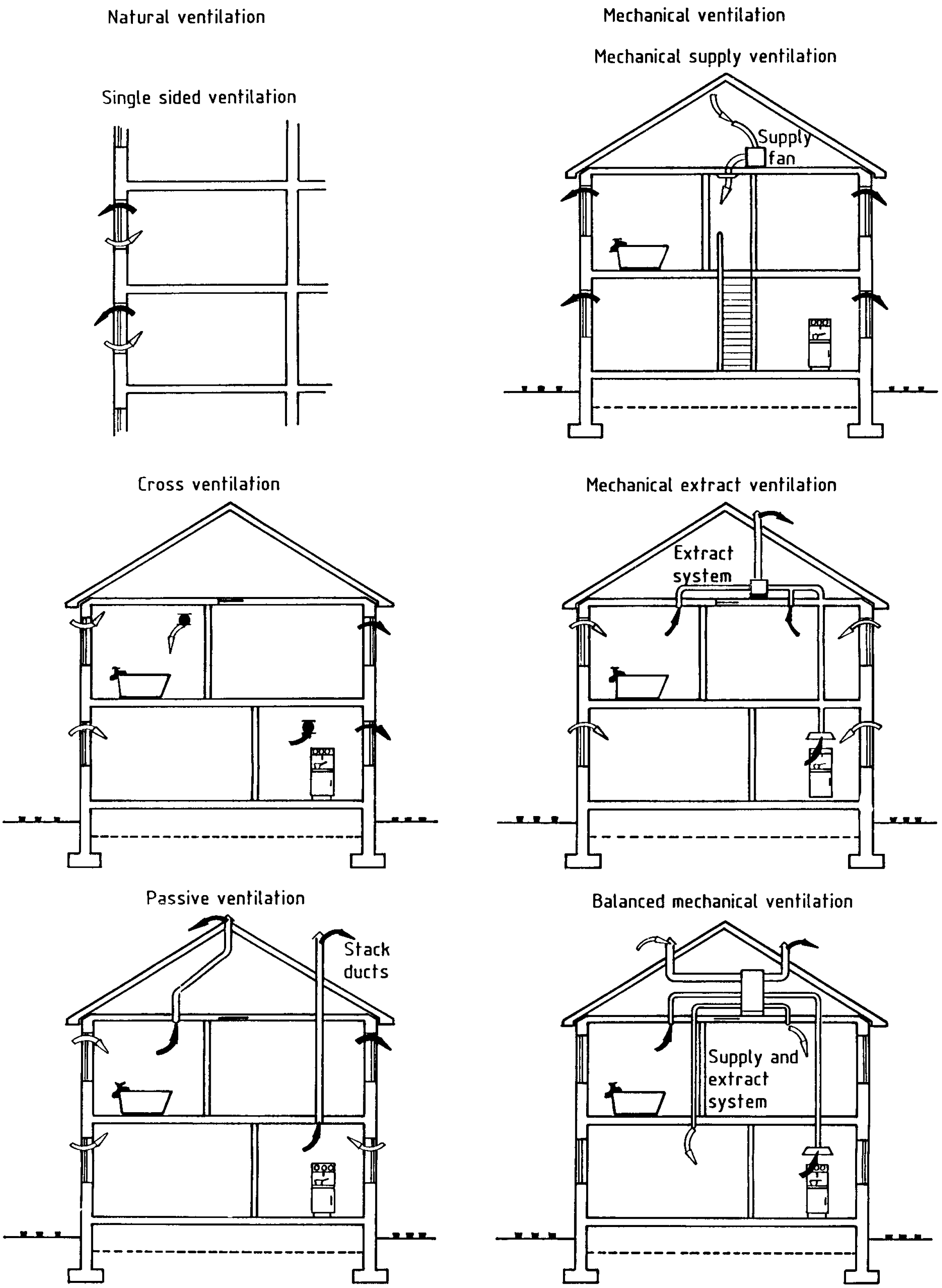
b) the pollutant mixes perfectly with the supplied air.

It should be recognized that these assumptions may not apply in all circumstances.

6.2.2 *Intermittent pollutant emission*

Equation (7) in Appendix B governs the change of pollutant concentration with time in a ventilated space for a pollutant emitted at a constant rate. The equilibrium concentration is determined only by the emission rate and the ventilation rate. The time taken to approach equilibrium is determined, however, by the ratio of the ventilation rate to the volume of the space, generally termed the air change rate. This is sometimes used as an alternative means of expressing a ventilation requirement where space volumes are known.

If the production of the pollutant is halted after a finite period of time, then the limiting concentration may not have been reached. This allows the possibility that minimum ventilation rates may be reduced for spaces in which pollutant emission takes place for only limited periods, as in the case of spaces, such as school halls, which may be occupied to full capacity for short periods during the day. Appendix B contains a simple method which allows the possible reduction to be calculated as a function of the period of emission and the space volume.



NOTE The same principles may be used in other types of buildings.

Figure 2 — Typical possibilities for inlets and outlets, for both natural and mechanical ventilation systems in dwellings

6.2.3 *Ventilation effectiveness*

The assumption that airborne pollutants are mixed uniformly throughout a ventilated space may not be true. Adequate mixing depends upon the condition of the supplied air and the location of entry points vis-a-vis the source of the pollutant.

In some cases the difference in density of the pollutant may encourage the formation of a stable layer which resists mixing with the air in the remaining part of the space.

In a naturally ventilated space good mixing can be promoted by appropriate distribution of the inlets and outlets. In mechanical systems attention may need to be paid to the design and position of supply and extract openings and the expected range of operating conditions to ensure good mixing under all circumstances. Attention should be paid to barriers within the space which might inhibit mixing.

6.3 Air movement

6.3.1 *General*

The method of air supply to a space, together with other sources of air movement in the space, such as hot and cold surfaces, can contribute to the movement of air and hence to the pattern of speed and temperature.

6.3.2 *Comfort criteria*

Air movement is noticed because it has a more cooling effect on the body than still air does. The lower limit of perceptibility is around 0.1 m/s.

Where air speeds in a room are greater than 0.1 m/s, the resultant temperature may have to be raised from its still air value to compensate for the cooling effects of the air movement (see Appendix A [10]). Figure 3 gives suggested corrections. Speeds greater than 0.3 m/s are probably unacceptable except in summer.

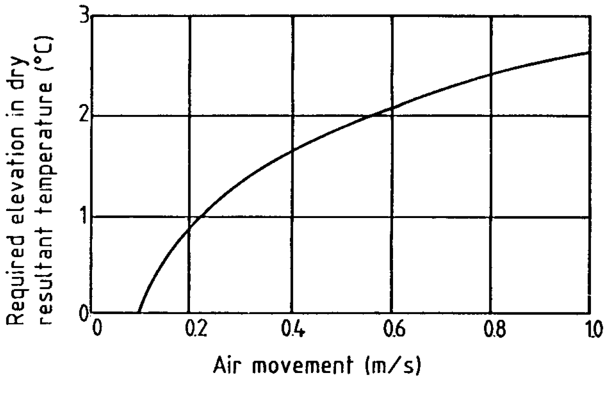


Figure 3 — Correction to the dry resultant temperature to take account of air movement
(Reproduced from reference [17], by permission of the Chartered Institution of Building Services)

7 Choice between natural and mechanical ventilation

7.1 Influencing factors

7.1.1 *General*

The basic factors which influence the choice between natural and mechanical systems are the quality, quantity and controllability of the ventilation.

7.1.2 *Quality*

There is often a difference between the cleanliness of the outdoor air and that indoors. Where the outdoor air is particularly polluted or where clean air is required indoors, the incoming ventilation air needs to be filtered. In applications where the exhaust air is significantly contaminated, filtration to remove the offending pollution is required before the air is discharged to outdoors.

7.1.3 *Quantity*

Clauses **4** and **5** give information on the fresh air flow rates required for rooms or spaces within buildings. In the less critical situations some variation in the rate of ventilation may be tolerable.

7.1.4 *Controllability*

In some circumstances variation in ventilation rate is desirable. For example, where substantial changes in numbers of occupants occurs, economies can be achieved by changing the rate of ventilation accordingly. In other cases, control of the direction of air flow, from clean to less clean areas, may be a specific requirement.

7.2 Limitations of natural ventilation

7.2.1 *Quality*

The scope for filtering or treating the supply of exhaust air is very limited with natural ventilation. This is because the flow-inducing pressures involved are low, so any increase in resistance to flow, for example imposed by filters, would substantially reduce the effectiveness of natural ventilation.

7.2.2 *Quantity*

In theory, almost any required quantity of outside air can be supplied by natural ventilation but, as recommended in **6.1.4**, account should be taken that this method is subject to practical limitations, in particular the variability of weather conditions. A low overall resistance to air flow is required to maximize the effectiveness of natural ventilation so its use is more appropriate in narrow buildings with limited internal partitioning. If necessary, such buildings could be aligned to gain maximum effect from the prevailing winds. The variability of natural ventilation arising from the dependence on the weather means that it is not suitable for applications requiring consistent flow rates. It follows that the acceptable degree of variation from the design requirement is a major determinant affecting the choice of natural ventilation.

7.2.3 *Controllability*

Precise control is not achievable with natural ventilation. Coarse control can be effected with openable windows, for example, but changes in speed and direction of the wind impose considerable fluctuations in flow rate. Further information may be found in Appendix A (17).

7.3 Need for mechanical ventilation

7.3.1 *Absolute necessity*

Mechanical ventilation is an absolute necessity in rooms or spaces requiring ventilation which cannot be adequately supplied by natural means, such as:

a) industrial or other premises where it is essential to remove dust, toxic or noxious contaminants at or near to their source;

b) hospitals where it is essential to control cross-infection, for instance in special care units, and to reduce the level of airborne bacteria in operating theatres;

c) where unfavourable external environment conditions, e.g. noise, dust, pollution, exist;

d) garages or enclosed car parks and vehicle tunnels, in order to remove exhaust gases, particularly carbon monoxide, petrol vapour and smoke in the event of a fire.

7.3.2 *Desirability*

Situations where it is desirable that mechanical ventilation should be provided are as follows:

a) factories and industrial processes in order to remove contaminants;

b) dwellings, in order to remove odours and excessive moisture from bathrooms and kitchens;

c) assembly halls and lecture theatres where a high density of occupation is expected;

d) situations where wind and stack effect might render natural ventilation impracticable, as with some tall buildings;

e) large commercial kitchens.

Section 3. Natural ventilation

8 General

The purpose of this section is to outline the physical processes which govern natural ventilation and to illustrate these for simple cases. The equations which describe these processes can be combined with meteorological data and building characteristics (such as the size and positions of air flow paths in the building envelope) in models which allow natural ventilation rates to be calculated. For all but the simplest situations the necessary calculations will be best performed by computer. These models may be used to give guidance on the areas of opening required to ensure that fresh air requirements are satisfied.

9 Flow characteristics of openings

When a difference in pressure is applied across an opening, a flow of air takes place through the opening. The aerodynamics of this flow are complex but, by classifying openings within two general types, it is possible to specify simple formulae to relate the flow rate to the pressure difference. The categories are:

a) cracks, or small openings with a typical dimension less than approximately 10 mm;

b) openings with a typical dimension larger than approximately 10 mm.

Taking each of these in turn:

For cracks, flow can be described in two ways, as a quadratic flow equation (see Appendix A[19]) or, more commonly, in the flowing form:

$$Q = kL(\Delta p)^n \tag{1}$$

L is the length of the crack in metres, and the Δp is the applied pressure difference in pascals (N/m^2). Table 5(a) (see also Appendix A [20]) gives a range of values of k for the cracks formed around the opening lights of commonly occurring types of windows when closed. A suitable value for n is 0.67. BS 6375-1 defines four classes of windows in relation to air permeability and gives guidance on their application. Table 5(b) lists the values of k which correspond to these classes, for use as an alternative to the values given in Table 5(a) in those cases where windows are known to comply with BS 6375.

Table 5 — Values of *k* for windows

(a) Values of *k* for windows (in L/s per metre of crack length for an applied pressure difference of 1 Pa)
(From reference [29])

Window type	*k*	
	Unweatherstripped mean (range)	**Weatherstripped mean (range)**
Timber	L/s per m at 1 Pa	L/s per m at 1 Pa
Side-hung casement	0.23 (1.19 to 0.04)	0.03 (0.10 to 0.01)
Top-hung casement	1.08 (1.38 to 0.88)	0.42 (1.22 to 0.11)
Centre-pivoted	0.80 (1.25 to 0.04)	0.02
Metal		
Side-hung casement	0.31 (0.45 to 0.21)	0.27 (0.29 to 0.14)
Top-hung casement	0.32 (0.55 to 0.18)	—
Vertically sliding	0.45 (1.20 to 0.20)	0.18 (0.34 to 0.04)
Horizontally sliding	0.22 (0.43 to 0.12)	—

(b) Values of *k* specified for different window exposure classifications (taken from BS 6375)

Window exposure classification	*k*
	L/s per m at 1 Pa
1 200 X or 1 200	0.130
1 600 or 2 000 and over	0.0992
Special	0.0258

For larger openings:

$$Q = C_\mathrm{d} A(2\Delta p/\rho)^{\frac{1}{2}} \qquad (2)$$

It is conventional to assign a value to the discharge coefficient, C_d, corresponding to that for a sharp-edged orifice, taken here as 0.61. The value of A for other types of opening then becomes the equivalent area associated with that particular opening, i.e. the area of the equivalent sharp-edged orifice which would give the same flow rate as the opening concerned at the same applied pressure difference. For openings such as open windows, whose depth in the direction of flow is much smaller than the typical lateral dimensions, the equivalent area can be taken as the geometrical area. For openings where this is not the case, equivalent areas may be determined experimentally. Table 6 gives values obtained for air-bricks and similar openings. (See also Appendix A [21]).

A building can be regarded as a series of discrete cells connected to outside air and to each other by openings of the types discussed. Usually these cells are rooms or circulation spaces, although floor, roof and wall voids may also need to be considered. Not all such cells are interconnected and some can be connected by more than one opening. Pressures generated by forces of wind and temperature difference produce a movement of air through these openings governed by the fact that the total flow of air into any cell should equal the outgoing flow rate. Clause **10** deals with the generation of pressure by wind and temperature difference.

10 Generation of pressure differences

10.1 Wind

The distribution of pressure at the surface of a building will depend upon the following:

a) the shape of the building;

b) the wind speed and direction relative to the building;

c) the location and surroundings of the building, particularly upstream terrain and the presence of other buildings or similar large obstructions in close proximity.

It has been found that, for any particular wind direction, the pattern of flow around a building is virtually independent of wind speed, provided that the building has sharp corners. The surface pressure will vary with wind speed squared, if all other conditions including wind direction remain constant. In consequence, the instantaneous pressure, p, generated at a particular point on the external surface can be defined in terms of a single coefficient, C_p, as follows:

$$C_\mathrm{p} = (p - p_\mathrm{o})/½\, \rho u_r^2 \qquad (3)$$

Table 6 — Equivalent area of ventilation openings

(Reproduced from reference [26]: Crown copyright HMSO)

Opening	Overall size	Equivalent area
	mm	mm^2
Terracotta air-brick with square holes	225 × 75	1 400
	225 × 150	4 300
	225 × 225	6 400
Terracotta louvred air-brick	225 × 150	2 000
	225 × 225	4 300
Cast iron air-brick with square holes	225 × 75	7 200
	225 × 150	12 700
	225 × 225	19 600
Cast iron air-brick	225 × 75	3 100
	225 × 150	11 300
	225 × 225	19 200
Typical internal louvred grille	225 × 75	2 400
	225 × 150	7 200
	225 × 225	10 700

p_o is the static pressure in the free wind, and u_r is the reference wind speed, conventionally taken as the speed of the undisturbed wind at a height equal to that of the building under consideration. The surface pressure varies with time, due to turbulence in the free wind and that created by the building itself, or by upstream obstructions, but for present purposes the mean value is used.

NOTE A brief discussion of the effect of pressure fluctuation on ventilation rate is included in clause **13**.

If the mean values of surface pressure and surface pressure coefficient are written as $\bar{p}$ and $C_{\bar{p}}$, equation (3) may be rearranged to give:

$$\bar{p} = p_o + C_{\bar{p}} \left(\frac{1}{2} \rho u_r^2\right) \qquad (4)$$

Once the distribution of $C_{\bar{p}}$ has been determined for a single wind speed and particular wind direction, then surface pressure can be calculated readily for any other wind speed. To illustrate the general magnitudes of $C_{\bar{p}}$, Table 7, taken from CP 3: Chapter V-2:1972, contains values for very simple building shapes. Most buildings are considerably more complex than these and are generally surrounded by other buildings or obstructions. To determine detailed distributions of pressure coefficient it will be necessary to resort to wind tunnel tests on scale models.

10.2 Temperature difference

Air density varies approximately as the inverse of absolute temperature. The weight of two vertical columns of air at different temperatures, separated from each other by a vertical surface, differs and a pressure difference across the surface results. Thus, if the air temperature within a building is higher than that outside, pressure difference creates an air flow through openings in the intervening fabric. Figure 4 illustrates the action of this pressure difference for a simple enclosure with one or two small openings. With a small single opening, no flow takes place. With two openings, air flows in at the lower opening and out at the upper opening, because the internal temperature is higher than that outside the enclosure. The pressure difference across the wall of the enclosure becomes such as to ensure that the inflow equals the outflow. The level at which the pressure difference is zero is known as the "neutral" level.

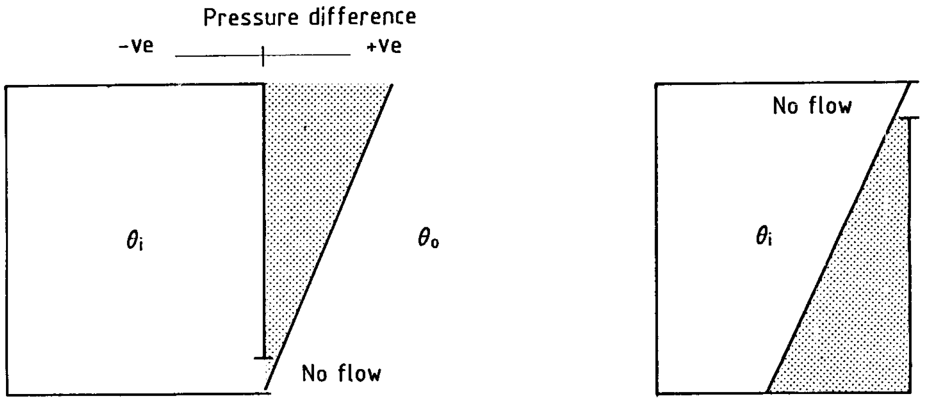
Table 7 — Typical magnitudes of pressure created by wind and temperature difference

(a) Wind

Wind speed (u_r)	**Pressure**			
	$C_p = 0.1$	**$C_p = 0.3$**	**$C_p = 0.5$**	**$C_p = 1.0$**
m/s	Pa	Pa	Pa	Pa
1.0	0.06	0.18	0.30	0.59
4.0	0.94	2.83	4.72	9.44
7.0	2.89	8.67	14.45	28.91
10.0	5.90	17.70	29.50	59.00

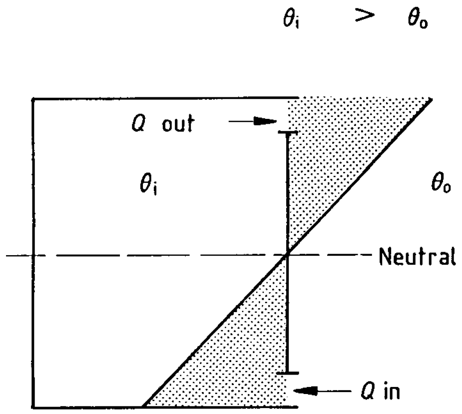
(b) Temperature difference

Temperature difference	**Pressure**					
	$H_1 = 1$ m	**$H_1 = 3$ m**	**$H_1 = 6$ m**	**$H_1 = 10$ m**	**$H_1 = 50$ m**	**$H_1 = 100$ m**
K	Pa	Pa	Pa	Pa	Pa	Pa
1.0	0.04	0.12	0.24	0.40	2.02	4.05
4.0	0.16	0.49	0.98	1.64	8.18	16.36
10.0	0.42	1.25	2.51	4.18	20.88	41.76
20.0	0.87	2.60	5.20	8.66	43.29	86.59



(a) Opening at base of enclosure

(b) Opening at top of enclosure



(c) Openings at both top and base of enclosure

Figure 4 — Pressure difference and flow created by temperature difference

11 Meteorological variables

11.1 General

A major problem with any attempt to predict natural ventilation rates is the variability with time of the governing agencies, i.e. wind and external temperature. Unless the physical aspects of the building can be modified to accommodate changes in these parameters, then natural ventilation rates will also vary considerably with time. Window opening and closing can act as a crude form of "modifier", particularly in summer, but in general it is necessary to consider the statistics of wind and temperature variation in order to choose suitable values for design purposes.

11.2 Wind

The natural wind is turbulent and its mean speed varies with height from the ground. The vertical profiles of wind speed and the turbulence characteristics vary with the stability of the atmosphere and the roughness of the terrain over which the wind is passing. Local topographical features such as hills and valleys can also affect wind profiles. All that will be considered here is the variation of mean wind speed with height (see Appendix A [22]). For different types of terrain, the following formula may be used:

$$u/u_{\mathrm{m}} = Kz^{a} \qquad (5)$$

u is the wind speed at height z; u_{m} is the wind speed measured at a large number of sites in the UK by the Meteorological Office, and is quoted for an equivalent height of 10 m in open countryside. The constants, K and a, depend upon the terrain and are given in Table 8. Given u_{m} and the type of terrain, it is therefore possible to estimate the speed of the undisturbed wind at any height, z.

Table 8 — Factors for determining mean wind speed at different heights and for different types of terrain from the Meteorological Office wind speed, u_m, measured at 10 m in open country (Reproduced from reference [26]: Crown copyright HMSO)

Terrain	K	a
Open flat country	0.68	0.17
Country with scattered wind breaks	0.52	0.20
Urban	0.35	0.25
City	0.21	0.33

It is now necessary to consider the geographical and statistical variation of u_m. Data on mean wind speed has been condensed (see Appendix A [23]) to provide a description of the cumulative frequency of wind speed in terms of the wind speed exceeded for 50 % of the time at a particular site. This value of u_m will be referred to as u_{50}. Figure 5 is a map of the UK showing contours of u_{50}. Used in conjunction with the frequency distributions given in Table 9, it is possible to determine the value of u_m exceeded for any chosen proportion of time at any site in the UK. In order to obtain this simplified relationship it has been assumed that the frequency distribution of wind speed at any site is independent of wind direction. This varies considerably at most sites in the UK but predominant directions can be obtained from wind "rose" maps (see Appendix A [24]).

Table 9 — Values of the ratio of mean wind speed exceeded for a given percentage of time to the 50 % mean wind speed u_{50} (Reproduced from reference [26]: Crown copyright HMSO)

Percentage	Location	
	Exposed coastal	Sheltered inland
80	0.56	0.46
75	0.64	0.56
70	0.71	0.65
60	0.86	0.83
50	1.00	1.00
40	1.15	1.18
30	1.33	1.39
25	1.42	1.51
20	1.54	1.66
15	1.70	1.80
10	1.84	2.03

The preceding information enables the reference wind speed, u_r, defined in clause **10**, to be estimated for any given site. Appendix E illustrates this by means of a simple example.

11.3 Temperature

Ambient air temperature varies diurnally and from day to day, but can, for present purposes, be characterized by a monthly mean and a monthly mean daily variation for any particular site. Table 10 shows the monthly mean air temperature for 12 sites. For further data see Appendix A (25), (26) and (27). An indication of the way in which the temperature varies over 24 h can be obtained from Appendix A (24) which shows the daily mean temperature variation for Heathrow, London, together with the standard deviation associated with these means. For design purposes it is suggested that the monthly mean value be used.

12 Determination of natural ventilation rates

12.1 General considerations

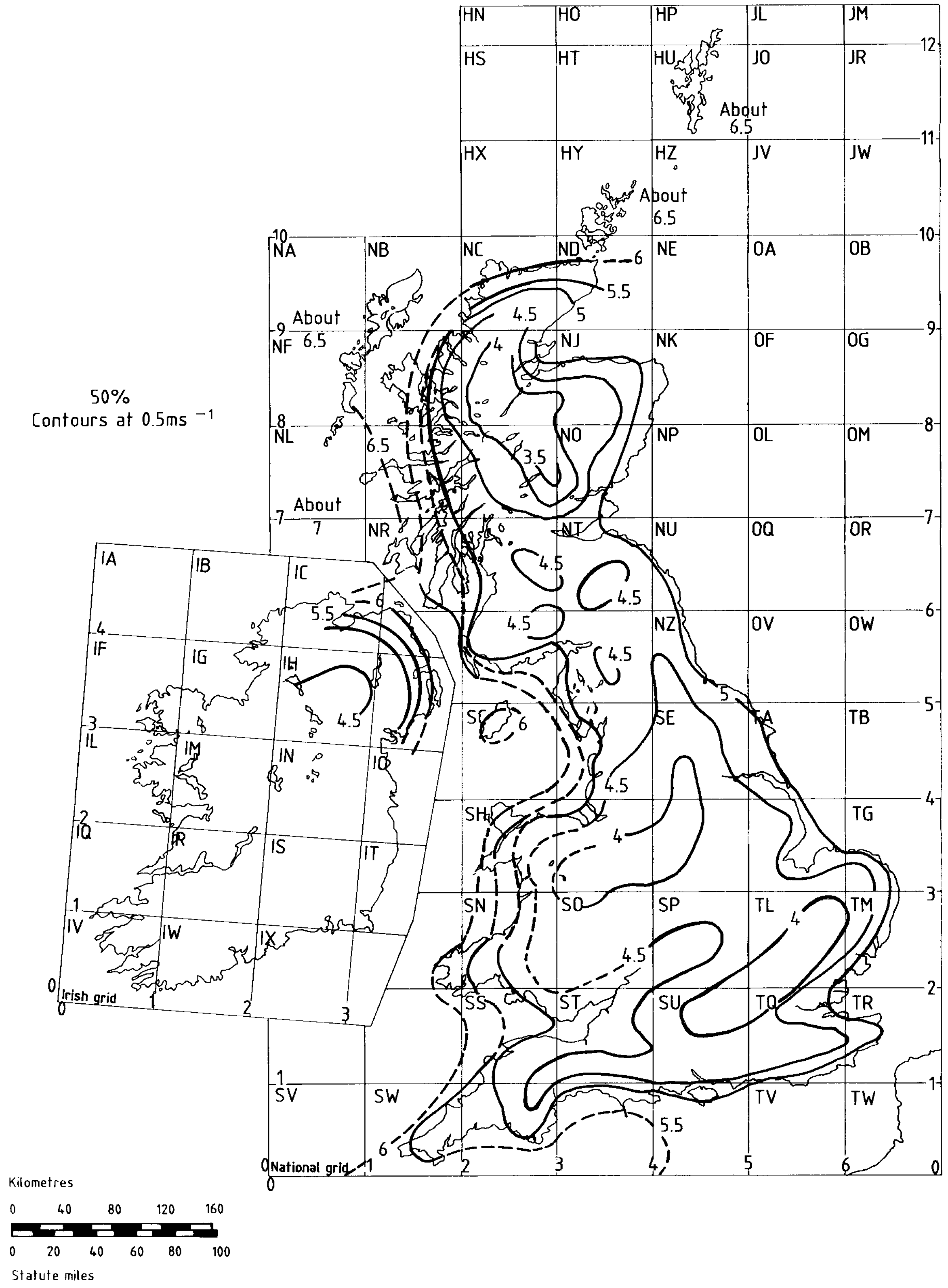
In principle, the foregoing information enables the air flow through a building and, in consequence, the ventilation rate of spaces within the building to be estimated for a given wind speed and direction, provided that the following are known:

a) the position and flow characteristics of all openings;

b) the detailed surface mean pressure coefficient distribution for the wind direction under consideration;

c) the internal and external air temperatures.

Because, in order to predict ventilation rates, in all but the simplest cases, a large number of non-linear simultaneous equations require to be solved, it is generally necessary to use a computer. Programs exist but the value of the results which they produce will depend upon the accuracy of the data listed in a), b) and c) above. It is rare that these are known in detail for existing buildings, let alone at the design stage. General data on many relevant factors are contained in Appendix A (28), which also summarizes a range of calculation techniques. However, more information is required on the pressure distributions for typical building arrangements and the position and flow characteristics of openings.



Hourly mean wind speed (ms^{-1}) exceeded for 50 % of the time 1965 to 1973. Valid for an effective height of 10 m and a gust ratio of 1.60, and for altitudes between 0 m and 70 m above mean sea level.

Figure 5 — Contours of u_{50} for the UK

(Reproduced from [21] by permission of the Controller of Her Majesty's Stationery Office)

Table 10 — Mean daily[a] air temperatures for 12 sites in the UK, 1941 to 1970

(Data from reference [21])

Region	**North-East Scotland**	**West Scotland**	**Northern Ireland**	**Borders**	**West Pennines**	**East Pennines**
Site	**Aberdeen (Dyce)**	**Glasgow (Abbotsinch)**	**Belfast (Aldergrove)**	**Acklington**	**Manchester (Ringway)**	**Finningly**
	°C	°C	°C	°C	°C	°C
January	2.3	3.1	3.5	2.9	3.3	3.3
February	2.6	3.5	3.8	3.1	3.7	3.8
March	4.5	5.5	5.7	4.9	5.7	5.8
April	6.7	7.9	7.9	7.1	8.3	8.7
May	8.9	10.7	10.4	9.3	11.3	11.5
June	12.0	13.6	13.3	12.3	14.3	14.7
July	13.5	14.7	14.4	14.1	15.7	16.3
August	13.3	14.5	14.3	13.9	15.5	16.0
September	11.7	12.7	12.7	12.4	13.7	14.1
October	9.1	9.9	10.1	9.7	10.5	10.8
November	5.3	6.0	6.4	6.1	6.5	6.7
December	3.3	4.2	4.6	4.0	4.3	4.5
Annual	7.7	8.9	8.9	8.3	9.4	9.2

Region	**Midland**	**Wales**	**Thames Valley**	**Severn Valley**	**Southern**	**South-Western**
Site	**Birmingham (Elmdon)**	**Aberporth**	**London (Heathrow)**	**Bristol (Filton)**	**Bournemouth**	**Plymouth (Mountbatten)**
	°C	°C	°C	°C	°C	°C
January	3.1	4.7	3.7	3.9	4.3	5.9
February	3.3	4.6	4.3	4.2	4.5	5.5
March	5.4	6.3	6.5	6.3	6.5	7.1
April	8.1	8.2	9.4	8.9	9.1	9.2
May	11.0	10.7	12.5	11.7	11.8	11.5
June	14.1	13.3	15.8	14.9	14.9	14.3
July	15.9	14.7	17.4	16.5	16.6	15.9
August	15.5	14.9	17.0	16.1	16.5	15.9
September	13.4	13.7	14.9	14.1	14.6	14.5
October	10.2	11.2	11.5	11.1	11.7	12.1
November	6.3	7.9	7.2	7.1	7.7	8.7
December	4.1	5.9	4.8	5.1	5.5	7.1
Annual	9.7	9.7	10.4	10.0	10.3	10.7

[a] The values given are average, for each calendar month and for the year as a whole, of the daily mean temperature calculated as the arithmetic mean of the daily maximum and daily minimum values.

The general characteristics of natural ventilation can, however, be demonstrated by considering some simple cases. Figure 6 shows a simple, "two-dimensional" representation of a building with no internal divisions, and therefore consisting of a single cell, with openings as shown, i.e. two (A_1 and A_3) at high level, and two (A_2 and A_4) at low level. These openings will be considered to be large and, consequently, the flow through them will be governed by equation (2) given in clause **9**. Table 11 shows schematically the approximate pattern of air flow and gives the formulae from which the ventilation rate, Q_1, can be determined, for the following situations:

a) wind only;

b) temperature difference only; and

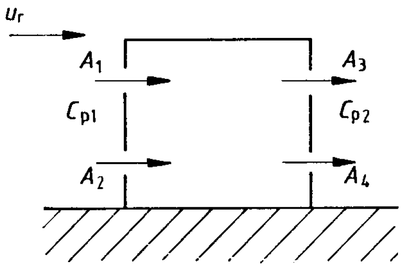
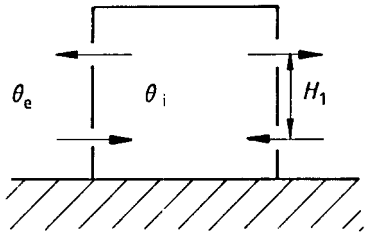
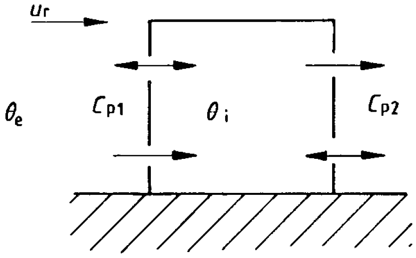
c) the combined effect of both.

These are discussed more fully in the following subclauses.

12.2 Wind only

Due to the difference in mean pressures between the windward and leeward faces, air flows in through the openings A_1 and A_2, and out through A_3 and A_4. A_w is the effective equivalent area of the four openings. It can be seen that openings in parallel can be added together arithmetically whilst those in series should be obtained from the reciprocal of their squares. It may also be noted that, as a consequence of equation (2), ventilation rate is proportional to wind speed and to the square root of the applied differential mean pressure coefficient, $\Delta C_{\bar{p}}$. Thus a range of $\Delta C_{\bar{p}}$ from 0.1 to 1.0, a ratio of 10, gives only a ratio of approximately 3 for the change in ventilation rate for the same wind speed. Higher values of $\Delta C_{\bar{p}}$ are typical of exposed building whereas lower values are more typical of sheltered buildings.

Table 11 — Natural ventilation of a simple building (Reproduced from reference [26]: Crown copyright HMSO)

Conditions	Schematic representation	Formula
(a) Wind only		$Q_w = C_d A_w u_r (\Delta C_p)^{1/2}$ $\frac{1}{A_w^2} = \frac{1}{(A_1 + A_2)^2} + \frac{1}{(A_3 + A_4)^2}$
(b) Temperature difference only		$Q_b = C_d A_b \left(\frac{2\Delta\theta g H_1}{\bar{\theta}}\right)^{1/2}$ $\frac{1}{A_b^2} = \frac{1}{(A_1 + A_3)^2} + \frac{1}{(A_2 + A_4)^2}$
(c) Wind and temperature difference together		$Q = Q_b$ For $\frac{u_r}{\sqrt{\Delta\theta}} < 0.26 \left(\frac{A_b}{A_w}\right)^{1/2} \left(\frac{H_1}{\Delta C_p}\right)^{1/2}$ $Q = Q_w$ For $\frac{u_r}{\sqrt{\Delta\theta}} > 0.26 \left(\frac{A_b}{A_w}\right)^{1/2} \left(\frac{H_1}{\Delta C_p}\right)^{1/2}$

NOTE It should be appreciated that, in practice, some openings exist unintentionally, e.g. junctions between building components, and that such openings will contribute to the ventilation actually achieved.

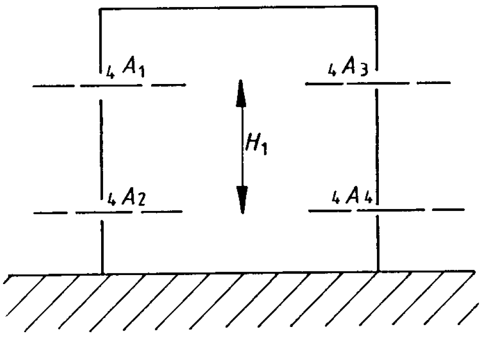


Figure 6 — Arrangement of openings in a simple building

12.3 Temperature difference only

In this case the air flows in at the lower openings A_2 and A_4 and out through A_1 and A_3. The equivalent area is now A_b. The formula given in Table 11 shows that ventilation rate is proportional to both temperature difference and height between openings.

12.4 Combined effect of wind and temperature difference

For the simple case under consideration, at low temperatures the flow pattern is similar to that for wind alone. If the temperature is increased, keeping wind speed constant, the combined effect of wind and temperature difference is to enhance the flow through the lower windward and upper leeward openings and to reduce the flow in the upper windward and lower leeward openings. Eventually, in this example, the flow in the upper windward and lower leeward openings becomes zero and as the temperature difference increases further it reverses, approaching a flow pattern typical of temperature difference acting alone.

Even for this simple example, the ventilation rate of the space due to the action of both wind and temperature difference is not easy to calculate, but a reasonable approximation can be made by calculating the flow rates expected for the two conditions acting separately and taking the larger to apply to the combined case. For the simple example in Figure 5 this leads to the expression $u_r/\surd\Delta\theta$ given in Table 11, which determines whether wind or temperature difference will dominate. The form of this expression indicates that taller, or more sheltered, buildings will tend to have natural ventilation rates independent of wind speed for a large part of the colder months of the year.

An example is given in Appendix F, using the formulae given in Table 11.

13 Other mechanisms of natural ventilation

13.1 General

Although the mechanisms of natural ventilation discussed in clause **12** apply in most situations, there are cases where other mechanisms are also of importance.

13.2 Natural ventilation of spaces with openings on one side only

13.2.1 *General*

To assist in dissipating heat and maintaining comfortable conditions, the ventilation rates required in non-air conditioned buildings in summer are higher than those required in winter.

These larger rates can usually be obtained readily by cross-ventilation according to mechanisms already discussed, except where large openings are available on one external wall only. Typical such examples are offices, or school classrooms, where internal doors are kept closed for reasons of privacy or noise. In these situations cross-ventilation would be severely restricted by the limited openings around the closed internal doors. In fact, considerable exchange of air can take place at the external wall openings due to the wind or temperature difference.

13.2.2 *Wind*

Air exchange at a single opening can occur because of the turbulent nature of the air flow, or due to the interaction of the local air flow with the opening light, say of a side-mounted casement window, Table 12 gives a simple formula which enables the flow rate to be calculated in terms of the open area of a window and the reference wind speed, u_r.

13.2.3 *Temperature difference*

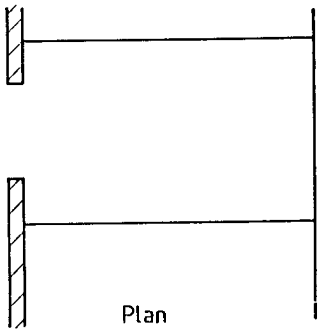
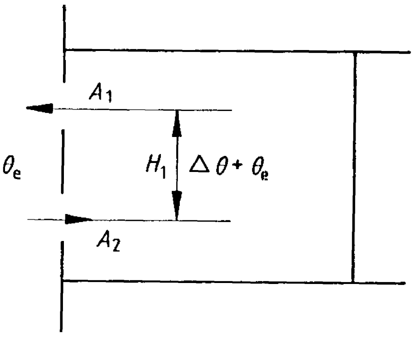
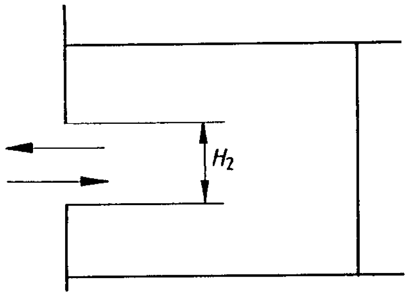
Temperature difference acts in the same way for a single room as for a building. The appropriate formulae for two openings, displaced vertically, and for a single rectangular opening are given in Table 12. For the single opening, warmer air flows out from the upper part of the opening and colder air in through the lower part of the opening. Figure 7(a) and Figure 7(b) show how the flow through a single opening window is modified by the presence of the opening light, for a side-mounted casement and a centre-pivoted window respectively.

13.2.4 *Combined wind and temperature difference*

As in the case of cross-ventilation, the ventilation rate due to both effects acting together can be taken as the larger of the two individual rates.

NOTE Appendix A (17) contains a graphical approach, based upon Table 11 and Table 12, for calculating ventilation rate for a number of simple building configurations in summer.

Table 12 — Natural ventilation of spaces with openings on one wall only (Reproduced from reference [26]: Crown copyright HMSO)

Conditions	Schematic representation	Formula
(a) Due to wind		$Q = 0.025Au_r$
(b) Due to temperature difference with two openings		$Q = C_dA \left[\frac{\epsilon\sqrt{2}}{(1+\epsilon)\ (1+\epsilon^2)^{1/2}}\right] \left(\frac{\Delta\theta g H_1}{\bar{\theta}}\right)^{1/2}$ $\epsilon = \frac{A_1}{A_2};\ A = A_1 + A_2$
(c) Due to temperature difference with one opening		$Q = C_d \frac{A}{3} \left(\frac{\Delta\theta g H_2}{\bar{\theta}}\right)^{1/2}$ If an opening light is present $Q = C_d \frac{A}{3} J(\phi) \left(\frac{\Delta\theta g H_2}{\bar{\theta}}\right)^{1/2}$ Where $J(\phi)$ is given in Figure 7

13.3 Pressure fluctuation

The turbulent nature of the wind, and additional turbulence created by the interaction of the building with the wind, mean that in practice the pressure generated at the surface of a building is not steady but fluctuating. The use of the mean pressures in clause **12** is, therefore, technically incorrect, but the error is small unless the mean pressure difference across an opening is small. Small pressure differences may arise from the effects of shelter, or the orientation of the building to the wind. Consider the example of a terraced house in the situation where the wind is parallel to the line of the terrace. The mean pressures at the two external faces would be equal. In practice turbulence gives rise to pressure fluctuations that can result in air flow through the house from alternating directions. The actual ventilation rate is therefore higher than that indicated by using Table 11 in conjunction with mean pressures. At present there is limited information available concerning this mechanism, but the available experimental results indicate, all other factors being equal, that the ventilation rate can be approximated by using a value of C_p of 0.2 in the formula given in Table 11.

14 Fire ventilation

The role of natural ventilation in relation to fire protection measures is firmly established in the context of "smoke control", particularly that associated with the protection of vertical escape routes. More recently, with the construction of complex enclosed shopping precincts, natural ventilation has been used to provide extraction systems for limiting the travel of smoke along covered malls (see Appendix A [28]). Roof vents in single-storey industrial premises were introduced earlier to restrict the spread of fire and smoke over large unobstructed floor areas (see Appendix A [29]).

Methods of providing ventilation of staircase shafts, lobbies, corridors and floor areas are:

a) permanent vents;

b) vents capable of being opened manually;

c) vents capable of being opened automatically.

NOTE See BS 5588.

15 Air infiltration

15.1 General

Air infiltration may be defined as uncontrolled natural ventilation through adventitious openings in the building envelope. Such openings may include the cracks around openable windows and doors but a high proportion occurs through other flow paths, particularly at the junctions of main building components. Infiltration rate may be measured using tracer gas techniques. The principles of these are introduced in **B.3**. In general these are fairly expensive and time-consuming and better suited to research applications. However, simple techniques now exist for estimating the overall envelope air leakage characteristics of small buildings such as houses and are being developed for larger industrial and commercial buildings. The air leakage characteristics so obtained may be used in conjunction with simple calculation techniques to estimate the air infiltration performance of a building.

15.2 Fan pressurization technique

The equipment for this technique consists of a fan unit, capable of being fitted into an appropriate opening, such as a doorway, in the building envelope and incorporating a method of measuring the flow rate of air through the fan. The fan is operated at a number of speeds to give a range of pressure differences, usually in the range 10 Pa to 100 Pa, across the building envelope. At each setting the flow rate is also measured. Both positive and negative pressure differences may be applied.

The results are conventionally expressed as a simple power law, of a form similar to equation (1):

$$Q = Q_{50}(\Delta p/50)^n \qquad (6)$$

where

Q_{50} is the leakage rate at a pressure difference of 50 Pa.

NOTE Other methods may be used to express the results of the fan pressurization test. These include the use of a quadratic relationship (see Appendix A [19]) or the formulation of an equivalent area.

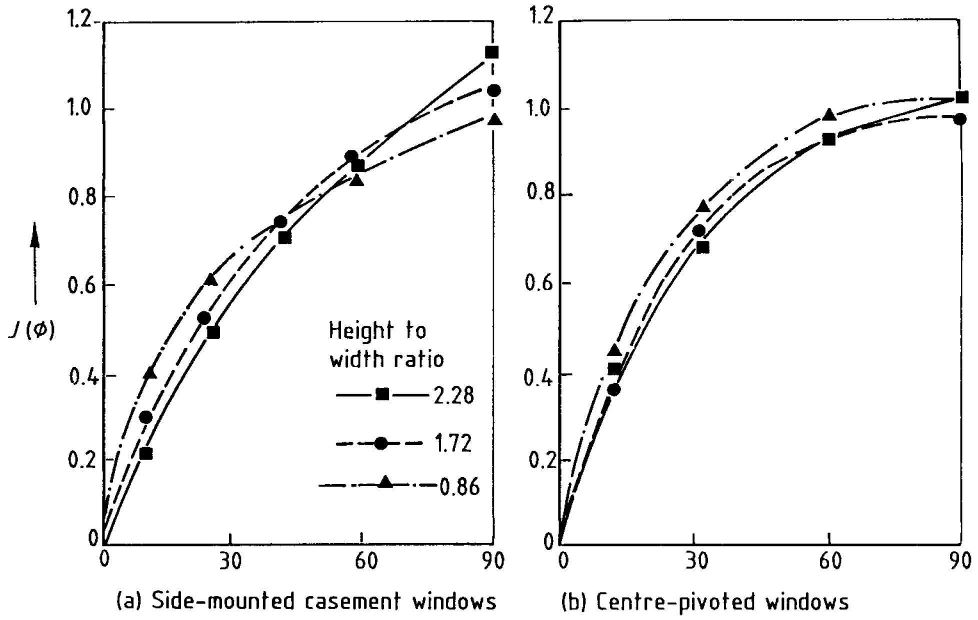


Figure 7 — Variation of $J(\phi)$ with angle opening ϕ for (a) side-mounted casement windows and (b) centre-pivoted windows

(Reproduced from reference [21]: Crown copyright HMSO) [see Table 12(c) for use of $J(\phi)$]

15.3 Application of the results to infiltration prediction

The data obtained from the pressurization test can be used in conjunction with simple computer models (see Appendix A [30]) to predict the infiltration performance of buildings for different climatic conditions. As a simple guide to the average heating season infiltration rate, **applicable to housing**, the value of Q_{50} can be divided by 20 times the internal volume of the house, V_h. Thus if Q_{50} is 3 000 m^3/h and the internal volume is 200 m^3 then an estimate of the average heating season infiltration rate would be 0.75 air changes per hour.

Typical values of Q_{50}/V_h for UK housing lie in the range 10 air changes per hour to 20 air changes per hour (see Appendix A [30]). At present there are insufficient data to indicate whether particular forms of construction, typically employed in the UK, can be associated with degrees of airtightness measured by the pressurization technique. It is, however, known from measurements made in other countries that values of Q_{50}/V_h of the order of 1.0 air changes per hour or less are achievable by appropriate design and quality control.

16 Normal building practice for natural ventilation in dwellings

16.1 General

The results of calculations of the ventilation rates required to control indoor pollutants, as described in Appendix B, Appendix C and Appendix D, may be relied upon with some confidence. However, as noted in **12.1**, the results of ventilation rate prediction calculations depend upon the accuracy of the input data used and it is rare that these data are known in detail for a particular building. Furthermore, the need for computer programs to deal with anything other than simple cases leads to the conclusion that there may often be insufficient benefits to justify making ventilation rate prediction calculations. This is particularly so in the case of small one-off buildings where the cost of gathering the required data may be prohibitive. Thus it is appropriate to give some guidance on normal building practice for natural ventilation.

Because of the variability of various construction features, such as ceiling heights, surface area/volume ratio, and type of wall construction, this guidance has to be limited to dwellings in which such features are more consistent. The guidance assumes that there exists a typical level of background air infiltration through adventitious openings in the building envelope. In dwellings which are of a type of construction which may be more airtight than normal, such as those with a particularly carefully fitted and jointed polyethylene vapour barrier, it may be necessary to increase the areas of the background ventilation openings to compensate for the reduced background air infiltration. Background air infiltration may be assessed using the method described in clause **15**.

Statutory and local regulations may be more or less stringent than the recommendations given in **16.2** and in all cases it is essential that such regulations take precedence. Furthermore, the recommendations of **16.2** may need to be modified to take account of individual circumstances; e.g. severity of exposure to weather, airtightness of the building structure, or requirements for protection against ingress of radon, methane or other soil gases.

16.2 Ventilation of dwellings

The following ventilation is recommended for rooms and spaces in and around dwellings.

a) *Habitable rooms*. For rapid ventilation one or more ventilation openings with a total area of at least 1/20th of the floor area of the room and with some part of the ventilation opening at least 1.75 m above the floor level, e.g. an opening window; and for background ventilation a ventilation opening(s), having a total area not less than 4 000 mm^2, e.g. a trickle ventilator. The opening(s) should be controllable and secure and located so as to avoid undue draughts.

b) *Kitchens*. Mechanical extract ventilation for rapid ventilation, rated as capable of extracting at a rate not less than 60 L/s (or incorporated within a cooker hood and capable of extracting at a rate of 30 L/s), which may be operated intermittently for instance during cooking; and either:

  1) background ventilation by a controllable and secure ventilation opening(s) having a total area not less than 4 000 m^2, located so as to avoid draughts, e.g. a trickle ventilator; or

  2) the mechanical ventilation being in addition capable of operating continuously at nominally one air change per hour.

c) *Bathrooms and shower rooms*. Mechanical extract ventilation capable of extracting at a rate not less than 15 L/s which may be operated intermittently.

d) *Common spaces in buildings containing two or more dwellings*. Ventilation by ventilation opening(s) with a total area of at least 1/50th of the floor area of the common space or communicating common spaces.

Where the space is wholly internal and is used for access only, mechanical extract ventilation capable of one air change per hour.

e) *Habitable rooms ventilated through other rooms and spaces*. Two habitable rooms may be treated as a single room for ventilation purposes if there is an area of permanent opening between them equal to at least 1/20th of the combined floor areas.

A habitable room may be ventilated through an adjoining space if:

  1) the adjoining space is a conservatory or similar space; and

  2) there is an opening (which may be closable) between the room and the space with an area not less than 1/20th of the combined floor area of the room and space; and

  3) there are one or more ventilation openings with a total area of at least 1/20th of the combined floor area of the room and space and with some part of the ventilation opening at least 1.75 m above the floor level; and

  4) for background ventilation there are ventilation openings to the space and openings between room and space, each having a total area not less than 4 000 m^2. The openings should be located so as to avoid undue draughts.

NOTE The openings recommended above are in addition to any openings required for the supply of combustion air to heat-producing appliances.

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Appendix B Calculation of contaminant concentration

B.1 Concentration of contaminant

The concentration, c, of a contaminant introduced at a constant rate into a ventilated space of volume, V, is given by:

$$c = \left(\frac{Qc_e + q}{Q + q}\right)\left[1 - e^{-\left(\frac{Q + q}{V}\right)t}\right] \tag{7}$$

where

q is the inflow rate of the contaminant (in L/s);

V is the volume of the ventilated space (in L);

Q is the volume flow rate of the outside air (in L/s);

c_e is the concentration of contaminant in the outside air;

t is the time (in s) from the moment the inflow of contaminant starts.

The ratio, Q/V, is usually termed the ventilation rate, R, and is measured in air changes per h. As t increases, the concentration reaches an equilibrium value, c_E, given by the equation:

$$c_E = \left(\frac{Qc_e + q}{Q + q}\right) \tag{8}$$

It should be noted that c_E depends upon the volume flow rate of the outside air, Q, and not upon the room volume, V. The room volume affects only the rate at which c approaches the value c_E.

The rate of air flow Q required to give the equilibrium concentration, c_E, is:

$$Q = q\left(\frac{1 - c_E}{c_E - c_e}\right) \tag{9}$$

If the incoming air is free of contaminant, i.e. $c_e = 0$, then the expressions simplify. Equation (7), with some rearrangement, becomes equation (10) below, and this leads to Figure 8.

$$c = \left(\frac{1}{1 + Q/q}\right)\left[1 - e^{-(1 + Q/q)\left(\frac{\mathrm{qt}}{\mathrm{V}}\right)}\right] \tag{10}$$

If $q = 0$, but there is present an initial concentration, c_o, of contaminant, then the rate of decay of concentration is given by:

$$c = c_o e^{-Rt} \tag{11}$$

B.2 Intermittent contaminant emission

The ventilation rate, Q, given by equation (9) is independent of the magnitude of the volume, V, of the space. This volume does, however, affect the rate at which the equilibrium level is achieved. This may be important in relation to situations where the emission of a pollutant is for a limited period only, say of length t_1. In such a case, if the space were ventilated at the rate, Q, calculated according to equation (9), then the concentration would fall short of the maximum allowable value, set equal to c_E. In principle, this allows a reduction in the magnitude of the minimum ventilation rate to a new value Q^r, given by:

$$Q^r/Q = F(Qt_1/V) \qquad (12)$$

The form of the function $F(Qt_1/V)$ is given in Figure 9. It will be noted that for values of $(Qt_1/V) < 1$, no ventilation at all is theoretically required. This is not practical since it is unlikely, however limited the time period, t_1, that the pollutant will not be emitted at some later time.

This may be taken into account by considering a regular, intermittent emission for a period of length, t_1, at intervals of length, t_2. The ratio of the modified minimum ventilation rate, Q^r, to Q is then a function of both (Qt_1/V) and the ratio, r, equal to (t_2/t_1). Figure 10 gives curves for calculating Q^r given these parameters.

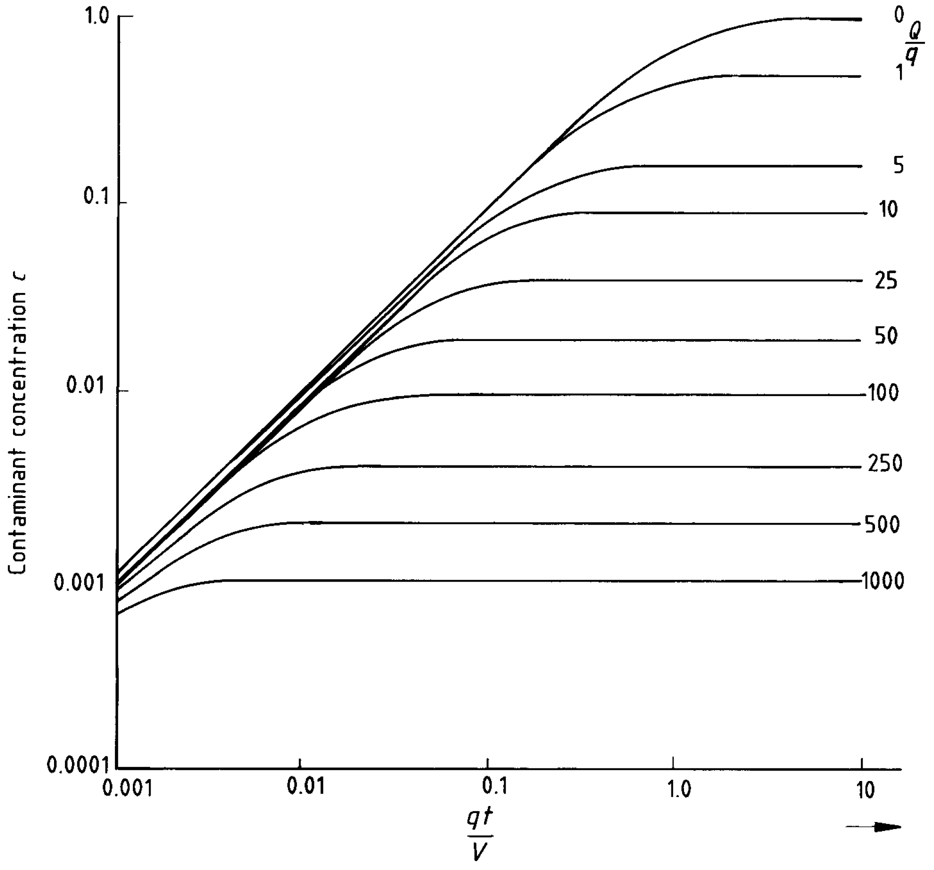


Figure 8 — Variation of gas concentration *c* with *t* and ventilation rate *Q* for gas leakage rate *q* (Reproduced from reference [6]: Crown copyright HMSO)

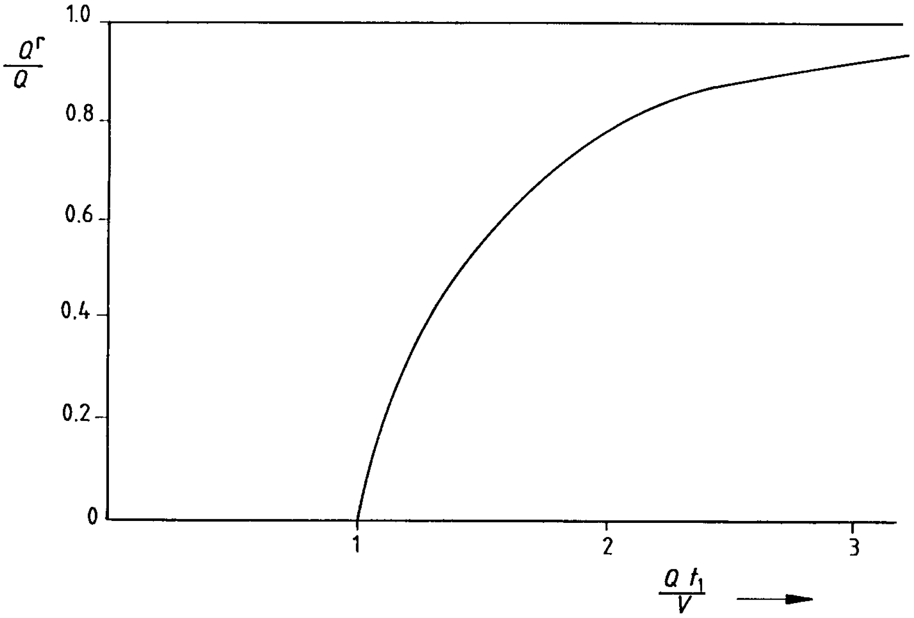


Figure 9 — Allowable reduction in minimum fresh air supply rate when the pollutant source is present for a limited period, t_1, rather than continuously

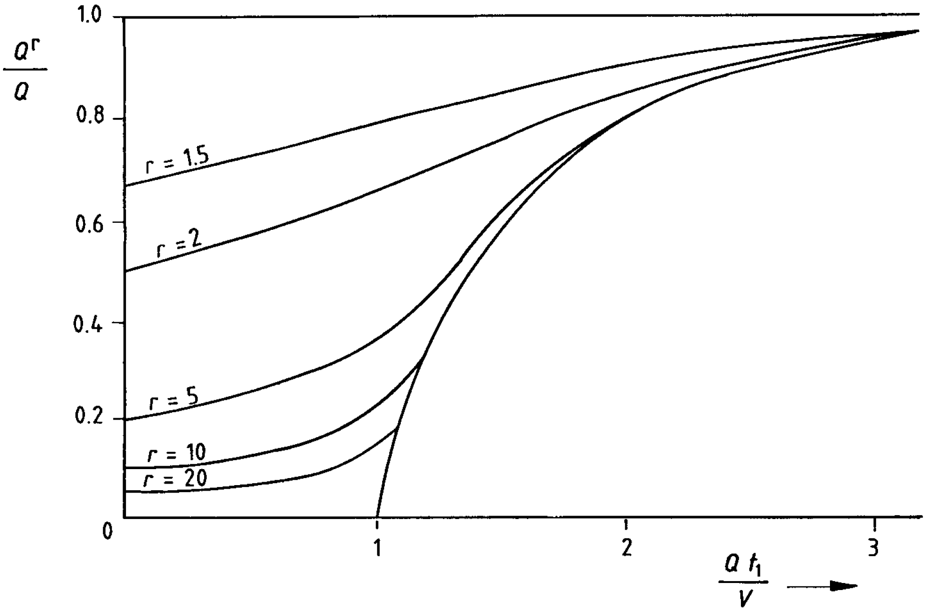


Figure 10 — Allowable reduction in minimum fresh air supply rate when the pollutant source is intermittent, being present for a length of time, t_1, with a return period, t_2 ($r = t_1/t_2$)

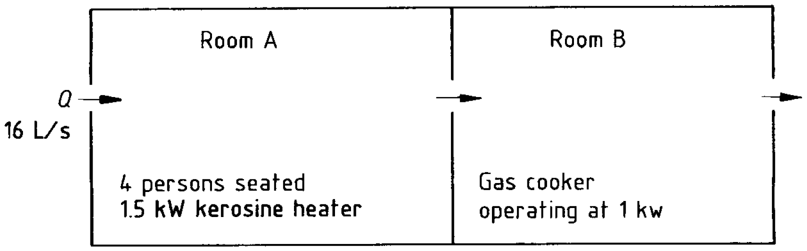


Figure 11 — Interconnecting spaces

B.3 Measurement of ventilation rate

Measurement of ventilation rate is not easy but can be achieved using a tracer gas, providing that good mixing is obtained, by the following methods.

a) *Decay rate.* A suitable quantity of tracer gas is liberated within the space and allowed to mix well. The concentration is monitored with time and the ventilation rate, R, determined using equation (11).

b) *Continuous injection.* Tracer gas is liberated into the space at a constant measured rate. The equilibrium concentration is measured. Equation (9) enables Q to be calculated and the additional knowledge of V gives the ventilation rate, R.

c) *Constant concentration.* This technique is appropriate for buildings consisting of a number of interconnected spaces. Equipment is required which enables tracer gas concentration to be measured in each space and a controlled quantity of gas to be injected into each space. The system is operated to maintain the concentration of tracer gas in each space at the same, predetermined level. The quantity of gas injected over a given period (typically 30 min) is proportional to the quantity of outside air entering over the same period.

B.4 Example calculation

Figure 11 shows a simple arrangement of two rooms in series. These are ventilated at a volume flow rate of 16 L/s. Room A contains four people seated quietly and a 1.5 kW flueless kerosine heater. Room B contains a gas cooker operating at 1 kW. Calculate the equilibrium concentration of carbon dioxide in each room with:

a) the kerosine heater off;

b) the kerosine heater on.

From Table 3, the input rates of carbon dioxide for the fuel-burning appliance are as follows:

gas cooker	0.027 L/s per kW input
kerosine heater	0.037 L/s per kW input

The input rate from respiration is given in **4.3**:

human breathing	$0.00004M$ L/s per person (M is the metabolic rate in watts)

Case (a). The input rates are as follows:

Room A : $(0.00004 \times 100 \times 4)$ L/s = 0.016 L/s

Room B = 0.027 L/s

The concentration of carbon dioxide in the outside air is 0.04 %. To calculate the concentration in room A, substitute the following values into equation (8):

Q = 16 L/s; $c_e = 0.0004$; $q = 0.016$ L/s;

$$c_E = \frac{(16 \times 0.0004) + 0.016}{16 + 0.016}$$

$$= 0.0014 \text{ (i.e. } 0.14\ \%)$$

To calculate the concentration in room B substitute the following into equation (8):

Q = 16 L/s; c_e = 0.0014; q = 0.027 L/s;

$$c_E = \frac{(16 \times 0.0014) + 0.027}{16 + 0.027}$$

= 0.0031 (i.e. 0.31 %)

Case (b). There is now an additional input of carbon dioxide from the heater equal to (0.037 × 1.5) L/s which equals 0.056 L/s. Thus resubstituting into equation (8) the concentration in room A is given by:

Q = 16 L/s; c_e = 0.0004;

q = 0.072 L/s (i.e. 0.056 + 0.016)

$$c_E = \frac{(16 \times 0.0004) + 0.072}{16 + 0.072}$$

= 0.0049 (i.e. 0.49 %)

The concentration in room B is given by:

Q = 16 L/s; c_e = 0.0049;

q = 0.027 L/s

$$c_E = \frac{(16 \times 0.0049) + 0.027}{16 + 0.027}$$

= 0.0066 (i.e. 0.66 %)

It is apparent that in case (b) the concentration in room B is higher than the 0.5 % recommended in clause **4**. In consequence, a higher ventilation rate is required than would be needed if each room were considered separately.

Appendix C Calculation of ventilation rates to reduce the risk of surface condensation under steady state conditions

The nomograph (Figure 1) is used in the following way.

a) Start in quadrant A. Choose outside air temperature and traverse vertically upwards to meet the chosen outside relative humidity. Traverse horizontally to the left into quadrant D, noting the position of this line for later use.

b) Enter quadrant B from the top by drawing a line from the chosen outside air temperature to the chosen inside air temperature (on scale below quadrant A) and extend to meet the top of quadrant B. Traverse vertically down in quadrant B and then horizontally into quadrant C from the line for the chosen “U” value for outside wall or window.

c) In quadrant C, traverse vertically upwards into quadrant D from the line for the chosen inside air temperature.

d) The intercept in quadrant D of the last line with that found in (a) above will, by reference to the sloping lines, give the minimum volume of outside air required per kilogram of moisture generated in the space to avoid condensation on the surface being considered.

Appendix D Determination of ventilation requirements

D.1 Example

Consider a domestic living room:

Size:	dimension 3.5 m by 4 m by 2.3 m high floor area 14 m^2 volume 32 m^3
Occupancy:	six adults metabolic heat production 125 W each respiratory moisture 0.05 kg/h each smoking three cigarettes per h
Heating:	1 kW flueless kerosine heater
Internal conditions:	20 °C 60 % r.h. (8.8 g/kg dry air)
External conditions:	a) 5 °C 95 % r.h. (5.2 g/kg dry air) 0.04 % CO_2, no other contaminants b) 10 °C 90 % r.h. (6.9 g/kg dry air) CO_2 as in (a)

D.2 Required ventilation rates for different purposes

a) *Control of carbon dioxide*

Sources of carbon dioxide are:

1) human respiration; and

2) operation of the kerosine heater.

The emission rates from these sources are as follows:

i) respiration (from Table 1): $6 \times 125 \times 40 \times 10^{-6} = 0.03$ L/s

ii) kerosine heater (from Table 3): 0.034 L/s

This gives a total of 0.064 L/s

Taking 0.5 % as the desired maximum concentration, then substitution, as follows, into equation (9) leads to a required outside air rate, Q:

$$Q = 0.064 \left(\frac{1 - 0.0004}{0.005 - 0.0004} \right)$$

Required ventilation rate for CO_2 is 13.9 L/s.

b) *Control of body odour*

On the basis of the 8 L/s per person the required ventilation rate is 48 L/s.

c) *Control of tobacco smoke*

If control of odour is taken as the criterion, then on the basis of a smoking rate per h the required ventilation is 360 m^3/h which is equal to 100 L/s.

d) *Control of sulphur dioxide*

From Table 3, the required flow rate to ensure that sulphur dioxide level does not exceed 1.0 ppm is 6.0 L/s.

e) *Control of humidity*

Sources of water vapour are:

1) human respiration; and
2) the kerosine heater.

Emission rates are as follows:

i) Respiration: 6 × 0.05 kg/h = 0.30 kg/h
ii) Kerosine heater: 0.10 kg/h

Thus, total water vapour emission rate is 0.40 kg/h

The required flow rate may be obtained by substitution in equation (9), taking care to ensure that the units for the various quantities are compatible, i.e. water vapour concentration is generally expressed in terms of g/kg dry air.

For case (a):

$c_e = 5.2$ g/kg; $c_E = 8.8$ g/kg

Then required outside air supply rate (kg/h) is given by:

$Q = 0.40\ [(1 - 0.0052)/(0.0088 - 0.0052)] = 110.5$ kg/h

Taking the density of dry air at 20 °C as 1.2 kg/m^3, this gives a required ventilation rate of 25.5 L/s.

For case (b):

$c_e = 6.9$ g/kg; $c_E = 8.8$ g/kg

Then required outside air supply rate (kg/h) is given by:

$Q = 0.40\ [(1 - 0.0069)/(0.0088 - 0.0069)] = 209.1$ kg/h

Taking the density of dry air at 20 °C as 1.2 kg/m^3, this gives a required ventilation rate of 48.3 L/s.

Summary

The required ventilation rates for the range of possible criteria set out in Appendix D may be summarized as follows.

1) Carbon dioxide [< 0.5 %(*V*/*V*)]:	14 L/s
2) Body odour:	48 L/s
3) Tobacco smoking (odour):	100 L/s
4) Sulphur dioxide (< 1.0 Vppm):	6 L/s
5) Water vapour (< 60 % r.h.)	
for case (a):	26 L/s
for case (b)	48 L/s

Thus, in this case, the dominant criterion is control of odour from tobacco smoke, leading to a ventilation requirement of 100 L/s, followed by control of body odour and water vapour which lead to values about one-half of this.

NOTE In this example only common contaminants have been taken into account.

Appendix E Calculation of reference wind speed u_r

E.1 Procedure

E.1.1 Ascertain the following data:

a) the geographical location of the building;
b) the proportion of the time for which the reference wind speed is to be exceeded;
c) category of terrain in which the building is situated;
d) height of the building.

E.1.2 Using a) in **E.1.1**, in conjunction with Figure 5, determine the value of u_{50}.

E.1.3 Using b) in **E.1.1**, in conjunction with Table 9, determine the appropriate ratio; multiply u_{50} by this to determine the free wind speed in open country exceeded for the given proportion of time, e.g. u_m.

E.1.4 Using c) in **E.1.1**, in conjunction with Table 8, obtain *K* and *a*.

E.1.5 Using these values in conjunction with u_m, as determined in **E.1.3**, substitute into equation (5), setting z equal to the height of the building, and hence determine u_r

E.2 Example

E.2.1 Determine the reference wind speed for the purposes of calculating natural ventilation rates, given that the chosen rate should be exceeded for 60 % of the time, for a building with a height of 30 m located in an urban area in the Midlands.

E.2.2 Summary of given data:

a) Location	Midlands
b) Proportion of time:	60 %
c) Terrain:	urban
d) Height:	30 m

E.2.3 From Figure 5, $u_{50} = 4.0$ m/s.

E.2.4 From Table 9, column 3, ratio for 60 % is 0.83, thus $u_m = 0.83 \times 4.0 = 3.3$ m/s.

E.2.5 From Table 8, for urban terrain, $K = 0.35$, $a = 0.25$.

E.2.6 Using equation (5)

$$u_r = u_m K z^a$$
$$= 3.3 \times 0.35 \times (30)^{0.25}$$
$$u_r = 2.7 \text{ m/s}$$

Appendix F Calculation of natural ventilation rates for a simple building

F.1 Example

Consider a building consisting of a single undivided space 25 m long, 10 m wide and 8 m high. Given that the building is situated in an open suburban area in the Manchester region, calculate:

a) the natural ventilation rate achieved for over 60 % of the time due to wind;

b) the ventilation rate due to the effect of a temperature difference of 6 °C in the absence of wind.

There are no ventilation openings on the shorter walls. On each of the longer walls there are openings of 2.5 m^2 at a low level, and 5.0 m^2 at a high level, separated by a vertical distance of 6.0 m, and evenly distributed along the length of the wall.

F.2 Procedures

a) Wind

1) Determination of pressure coefficient difference

Building height ratio = 0.8

Building plan ratio = 2.5

Thus, from Table 13, the difference in mean surface pressure coefficients at the two long sides of the building for a perpendicular wind is:

$$0.7 - (-0.3) = 1.0, \text{ i.e. } \Delta \bar{C}_p = 1.0$$

2) Determination of u_r

i) Location: Manchester region: thus from Figure 5, $u_{50} = 4.5$ m/s

ii) Proportion of time: 60 %: thus from Table 9, correction factor = 0.83.

iii) Terrain: country with scattered wind breaks: thus from Table 8, $K = 0.52$, $a = 0.20$.

Thus from equation (5), using the building height of 8 m,

$$u_r = 4.5 \times 0.83 \times 0.52 \times 8.0^{0.2}$$
$$= 2.9 \text{ m/s}$$

3) Determination of A_w

$$\frac{1}{A_w^2} = \frac{1}{(5.0+2.5)^2} + \frac{1}{(5.0+2.5)^2}$$

thus, $A_w = 5.3\ \text{m}^2$

4) Determination of ventilation rate

Using the formula in Table 11, section (a),

$$Q_w = 0.61 \times 5.3 \times 2.9 \times 1.0^{0.5}\ \text{m}^3/\text{s}$$

$$Q_w = 9.4\ \text{m}^3/\text{s}$$

The volume of the building is 25 m^3 × 10 m^3 × 8 m^3, i.e. 2 000 m^3

Thus the air change rate is 3 600 × 9.4/2 000 = 17 air changes/h

b) Temperature difference

From the information given: temperature difference = 6.0 °C; height between openings $H_1 = 6.0$ m

$$\frac{1}{A_b^2} = \frac{1}{(2.5+2.5)^2} + \frac{1}{(5.0+5.0)^2}$$

thus, $A_b = 4.5\ \text{m}^2$.

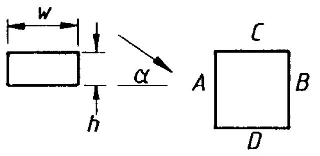
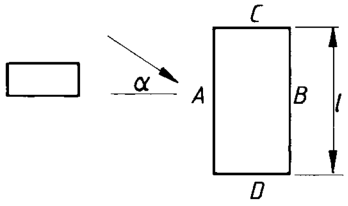
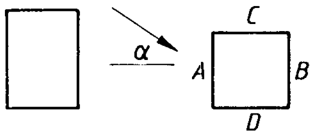
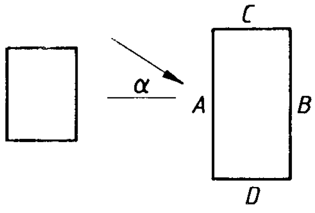
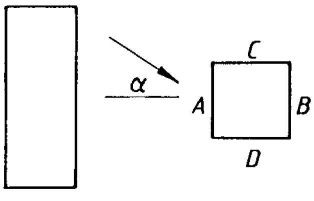
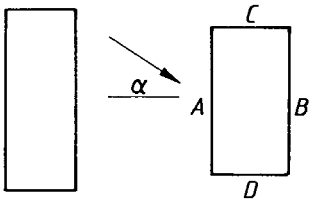
Taking $\bar{\theta} = 300$ K, and using the formula given in Table 11, section (b),

$$Q_b = 0.61 \times 4.5 \times (2 \times 6 \times 9.81 \times 6/300)^{0.5}$$

$$Q_b = 4.2\ \text{m}^3/\text{s}.$$

Thus, the air change rate is 3 600 × 4.2/2 000 = 7.6 air changes/h.

Table 13 — Mean surface pressure coefficients for vertical walls of rectangular buildings[a]

Building height ratio[b]	Building plan ratio[b]	Side elevation/Plan	Wind angle α	C_P for surface			
				A	*B*	*C*	*D*
$\frac{h}{w} \leq \frac{1}{2}$	$1 < \frac{l}{w} \leq \frac{3}{2}$		degrees 0	+ 0.7	– 0.2	– 0.5	– 0.5
			90	– 0.5	– 0.5	+ 0.7	– 0.2
	$\frac{3}{2} < \frac{l}{w} < 4$		0	+ 0.7	– 0.25	– 0.6	– 0.6
			90	– 0.5	– 0.5	+ 0.7	– 0.1
$\frac{1}{2} < \frac{h}{w} \leq \frac{3}{2}$	$1 < \frac{l}{w} \leq \frac{3}{2}$		0	+ 0.7	– 0.25	– 0.6	– 0.6
			90	– 0.6	– 0.6	+ 0.7	– 0.25
	$\frac{3}{2} < \frac{l}{w} < 4$		0	+ 0.7	– 0.3	– 0.7	– 0.7
			90	– 0.5	– 0.5	+ 0.7	– 0.1
$\frac{3}{2} < \frac{h}{w} < 6$	$1 < \frac{l}{w} \leq \frac{3}{2}$		0	+ 0.8	– 0.25	– 0.8	– 0.8
			90	– 0.8	– 0.8	+ 0.8	– 0.25
	$\frac{3}{2} < \frac{l}{w} < 4$		0	+ 0.7	– 0.4	– 0.7	– 0.7
			90	– 0.5	– 0.5	+ 0.8	– 0.1

[a] This table is based on a table in CP 3: Chapter V-2.

[b] *l* is the length of the major face of the building; *w* is the width of the building, i.e. length of the minor face.

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Publication(s) referred to

BS 2869, *Fuel oils for non-marine use.*

BS 5250, *Code of practice for control of condensation in buildings.*

BS 5410, *Code of practice for oil firing.*

BS 5410-1, *Installations up to 44 kW output capacity for space heating and hot water supply purposes.*

BS 5410-2, *Installations of 44 kW and above output capacity for space heating, hot water and steam supply purposes.*

BS 5440, *Installation of flues and ventilation for gas appliances of rated input not exceeding 60 kW (1st, 2nd and 3rd family gases).*

BS 5440-2, *Specification for installation of ventilation for gas appliances.*

BS 5588, *Fire precautions in the design, construction and use of buildings.*

BS 5643, *Glossary of refrigeration, heating, ventilating and air-conditioning terms.*

BS 5720, *Code of practice for mechanical ventilation and air conditioning in buildings.*

BS 6100, *Glossary of building and civil engineering terms.*

BS 6230, *Specification for installation of gas-fired forced convection air heaters for commercial and industrial space heating of rated input exceeding 60 kW (2nd family gases).*

BS 6375, *Performance of windows.*

BS 6375-1, *Classification for weathertightness (including guidance on selection and specification).*

BS 8207, *Code of practice for energy efficiency in buildings*1).

BS 8303, *Code of practice for installation of domestic heating and cooking appliances burning solid mineral fuels.*

CP 3, *Code of basic data for the design of buildings.*

CP 3:Chapter V, *Loading.*

CP:Chapter V-2, *Wind loads.*

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1) Referred to in the foreword only

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