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Ventilation requirements

The air in an enclosed space is likely to contain contaminants which may be unpleasant or even harmful to the occupants or which may cause deterioration of the fabric. This digest discusses fresh air requirements and tolerable levels of contamination from various sources and explains the calculation of dilution rates. It is concerned mainly with ventilation during the heating season. In summer, the rates required will generally be higher than those derived from the information given here because of the need to reduce temperatures in non-air-conditioned buildings.

Clean air

It is conventional to compare the quality of air within a space with 'fresh air' and it is important therefore to define this as a standard. Table 1 shows the major constituents of the atmosphere at ground level in open country. Outside air may of course be polluted by contaminants released into the atmosphere from industrial processes and the burning of fossil fuels for heating. In urban areas substantial local pollution may be created by road traffic, industrial premises and heating plants. Care must be taken, therefore, in any particular circumstance to take account of variation from the standard constitution of air shown in Table 1.

Table 1 Composition of dry atmosphere

Constituent	Percent by volume
Nitrogen	78·08
Oxygen	20·94
Carbon dioxide	0·03
Argon and other gases	0·95

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Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

Principles of dilution

Figure 1 shows a space of volume V ventilated by a supply of air at a rate Q. The general equation which describes the concentration c of a particular contaminant within the space at time t is:

$$c = \left[\frac{Qc_i + q}{Q + q}\right]\left[1 - e^{\frac{-(Q+q)\,t}{V}}\right] + c_o e^{\frac{-(Q+q)\,t}{V}} \qquad \ldots\ldots\ (1)$$

where: c is the concentration of contaminant at time t
c_o is the concentration of contaminant when $t = 0$
c_i is the concentration of contaminant in the incoming air
Q is the volume flow rate of ventilating air
q is the total volume flow rate of a particular contaminant from any sources within the space
(q Q V and t can be in any self-consistent system of units)

After a long time, the concentration reaches a steady or equilibrium value, c_e, given by:

$$c_e = \left[\frac{Qc_i + q}{Q + q}\right] \qquad \ldots\ldots\ (2)$$

If c_i and c_o are zero, ie the outside air is uncontaminated and the space contains no contaminants initially, equation (*1*) simplifies to:

$$c = \frac{q}{Q + q}\left[1 - e^{-\left(\frac{Q+q}{q}\right)\left(\frac{qV}{t}\right)}\right] \qquad \ldots\ldots\ (3)$$

This equation is the basis of Fig 2, which may be used to calculate the concentration at time t for given values of Q and q. The equilibrium concentration is given by:

$$c_e = \frac{q}{(Q + q)} \qquad \ldots\ldots\ (4)$$

Using equation (*4*), or equation (*2*) if the incoming air contains the contaminant, it is possible, given a limiting value for c_e and input rate q, to calculate the minimum required ventilation flow rate Q.

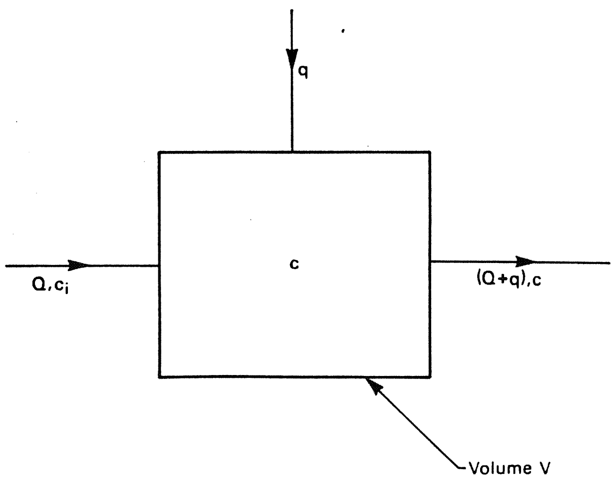

Fig 1 Contaminant entering a room of volume V at a rate q with fresh air ventilation Q

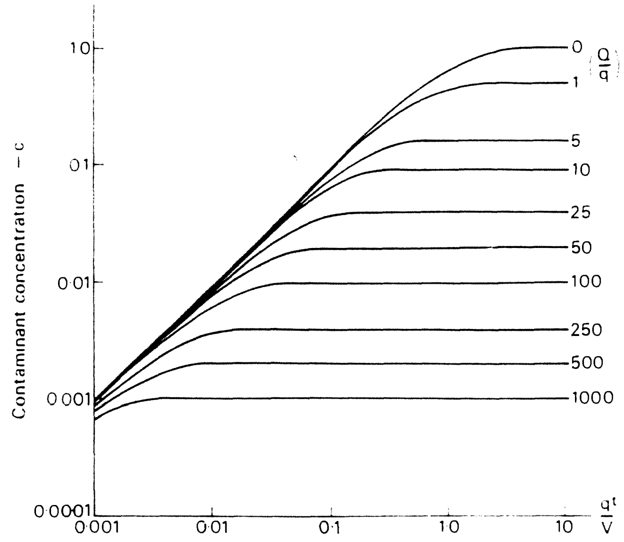

Fig 2 Variation of gas concentration c with t and ventilation rate Q for gas leakage rate q

Two particular points arise from the equations: the equilibrium value is independent of the initial concentration of contaminant within the space and the volume of the space affects only the rate at which equilibrium concentration is reached and not the equilibrium value itself.

The equations assume good mixing of the contaminant and the air within the space. However, this may not necessarily take place, particularly if there is a considerable difference in density between air and the contaminant and, as a result, a stable layer of contaminant may form. This can occur with heavy vapours such as petrol and liquified petroleum gases or light gases such as methane, the principal constituent of natural gas. Under these conditions, special care must be taken with the position and design of ventilation openings(1) to minimise the risk of unexpectedly high concentrations.

Contaminants

There are many possible contaminants and each will be associated with a limiting value of concentration either to prevent harm to persons inhaling them, to prevent the formation of an explosive mixture or to prevent deterioration of the fabric by biological or chemical action. The most common are given here, against their main sources.

Physiological	CO_2, H_2O, body odour
Combustion	CO_2, H_2O, SO_2 (from fully-burnt fuels)
	CO, CH_4, petrol vapour (from partially or unburnt fuels)
Tobacco smoking	Odour, CO, irritants
Household activities	H_2O, odours

The input rates of some of these contaminants can be defined with some certainty in relation to their source and are listed in Table 2. For others, particularly in relation to leakage of unburnt fuels, an estimate will have to be made from the prevailing circumstances.

Limiting values of common contaminants

Using the following limiting values, and those in Table 3, together with input rates from Table 2, the required flow rates of fresh air can be calculated for any situation. Limiting values for less common contaminants can be found in ref (2).

Table 2 Rates of production of common contaminants

Combustion

Fuel	Contaminant		
	Carbon dioxide *l/s per kW*	Water vapour *g/h per kW*	Sulphur dioxide *l/s per kW*
Natural gas	0·027	156	—
Kerosine	0·034	96	$8{\cdot}9 \times 10^{-6}$
LPG	0·033	130	—

Physiological

Activity (adult)	Contaminant	
	Carbon dioxide *l/s per person*	Water vapour *g/h per person*
Resting	0·004	30
Light work	0·006–0·013	40
Moderate work	0·013–0·020	40
Heavy work	0·020–0·026	—
Very heavy work	0·026–0·032	—

Tobacco smoking

Carbon monoxide	0·08 l/s per cigarette

Household activities *24 h average*

	Water vapour *g/day*
Cooking	3000
Bathing	1000
Dish washing	1000
Clothes washing	500
Clothes drying	5000

Carbon dioxide Up to four per cent has been found to be quite acceptable in inspired air but 0·5 per cent is the generally accepted limit. The amount of carbon dioxide in the supply air for combustion can affect burner performance and may, if too high, cause incomplete combustion and consequent excessive production of carbon monoxide. Again, the accepted limit is 0·5 per cent.

Carbon monoxide Carbon monoxide is a toxic gas in even small concentrations and the threshold limit value* is set at 50 ppm. Higher levels are tolerable for shorter exposure times. The limits of flammability (the range over which combustion is possible) are 12 to 75 per cent.

Sulphur dioxide The currently accepted threshold limit value is 5 ppm.

Water vapour Digest 110[(3)] indicates methods for reducing the risk of and designing to avoid both interstitial and superficial condensation. The starting point for these calculations, once internal and external dry bulb temperatures have been stipulated, is the moisture

* Threshold limit value is a time-weighted concentration for an average length working day over a 40-hour working week; see also ref (2).

Table 3 Limiting values of common contaminants

Contaminant	Limiting concentrations	
	Toxicity %	Flammability %
Carbon dioxide	0·5	–
Carbon monoxide	0·005	12·0–75·0
Sulphur dioxide	0·0005	–
Methane	30	5·0–15·0
Propane	30	2·0– 9·5
Butane	30	1·5– 8·5
Acetylene	30	2·5–82·0
Hydrogen	30	4·0–74·0
Petrol	0·10	1·4– 7·6

content of the internal air. This, therefore, produces the main limiting value for the concentrations of water vapour for use in ventilation calculations. Other limits on water vapour content may be expressed in terms of relative humidity: this can vary over a wide range although levels below 30 per cent or above 70 per cent may cause discomfort and levels above 70 per cent may encourage the growth of moulds.

Fuel gases Fuel gases such as methane (natural gas) are generally non-toxic but in concentrations above about 30 per cent symptoms of anoxaemia can be apparent. The limits of flammability for some fuel gases are given in Table 3.

Petrol Petrol vapour, which can occur from spillage, is toxic in concentrations of only 0·1 per cent. It is also extremely inflammable with flammability limits in the range 1·4 to 7·6 per cent.

Odours

Odours present a particular problem as they consist of a large number of constituent chemical components generally present in only small concentrations whose proportions are likely to vary. Attempts to define and measure odours chemically have generally been unsuccessful; in the case of tobacco smoke and body odours in particular, it has been found necessary to measure directly the air flow rates required to ensure a satisfactory air quality based upon the number of cigarettes being smoked or persons present. In general, tobacco odour dominates and masks body odour; a further complication is that with nearly all odours the human olfactory mechanism rapidly adapts and the perceived odour intensity drops rapidly from an initial value on entering a contaminated space to a lower, fairly steady level after a matter of minutes.

Body odour The fresh air supply necessary to maintain body odour at a satisfactory level depends upon standards of personal hygiene and differs between children and adults. Figures 3(a) and 3(b) show the required flow rates for school children and adults of average socio-economic status.[4] Two points should be noted. Firstly, the flow rate per person depends upon the density of occupation (the reason for this is not clear, but may be related to the rate of chemical breakdown of some of the constituents of body odour). Secondly, due to adaptation, very much lower flow rates are required if the level of odour is assessed by an occupant of the space rather than an observer newly entered from outside.

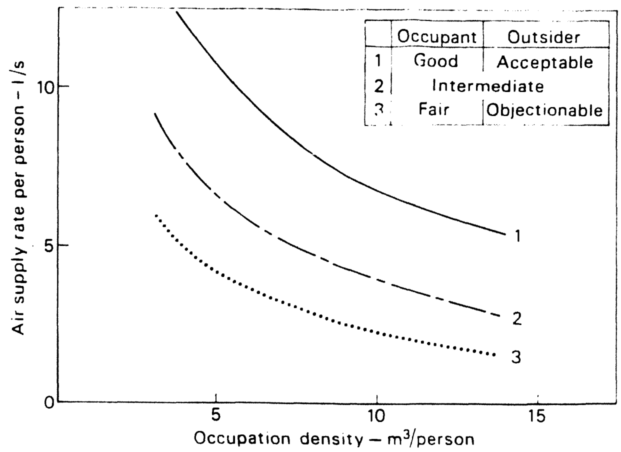

Fig 3(a) Air supply rate for odour removal—school children

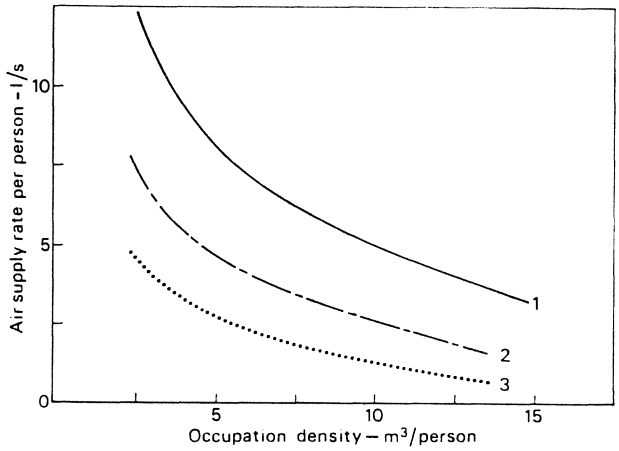

Fig 3(b) Air supply rate for odour removal—adults

Tobacco smoke Apart from carbon monoxide production the smoking of tobacco can produce an undesirable odour, particularly to non-smokers, and because of certain of its constituents, in particular acrolein, may produce irritation to the eyes and nasal passages. Research has shown that larger flow rates are necessary to combat the former and this will be used as the basis for deriving fresh air requirements.

A summary [5] of available research results indicates a considerable variation in recommended flow rates. In the absence of more definitive information, a value of 20 m^3 per cigarette smoked appears to be a reasonable compromise. To translate this into an air supply rate requires a knowledge of the number of smokers present and the rate of smoking. The average smoker consumes 1·3 cigarettes per hour: this requires a fresh air rate of 26 m^3/h or 7 l/s per smoker. As about 50 per cent of the adult population smoke, an allowance can be made for this in the design ventilation rate of spaces which are relatively heavily-populated, eg open-plan offices, which may have a lower required flow rate than cellular offices [5]. It also follows that if the smoking rate is expected to be more than 1·3 cigarettes per hour, appropriate corrections will need to be made.

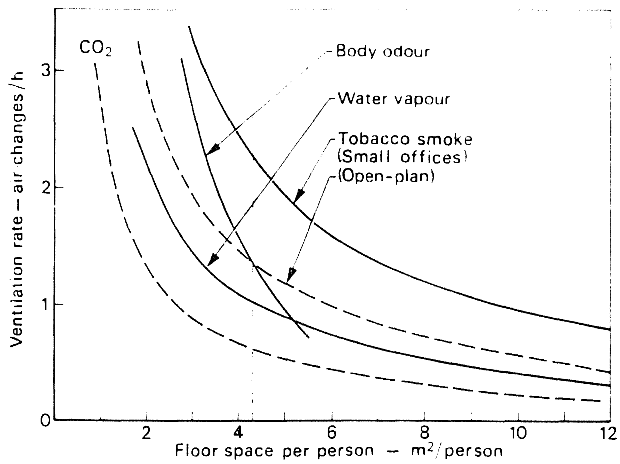

Fig 4 Ventilation requirements for offices
vertical dotted line shows lower limit as defined by Offices and Shops and Railway Premises Act (assuming ceiling height of 2·7m)

Total requirements

If the purpose and occupancy levels of a space can be defined then the foregoing sections enable a total ventilation requirement to be calculated. In most common cases satisfying the contaminant with the highest required ventilation flow rate will usually mean that others are also satisfied, ie individual flow rates are not usually additive. As an example, the requirements for given occupancy levels have been constructed for a typical office and are shown in Fig 4. For convenience of interpretation, they are presented in terms of air change rate for a given area of floor space per person. This requires the assumption of a floor to ceiling height, which for this example has been taken as 2·7m. Two lines are presented for tobacco smoke. For small offices it is assumed that air must be provided for the situation in which all occupants smoke, whereas for open-plan offices some allowance is made for the probability that only a proportion of the occupants are smokers.

In many situations, and particularly in dwellings, input rates depend greatly on the pattern of occupation and habits which are much less easy to define than the example of the office given here. In these cases, the accurate definition of required air flow rate may have to await the results of behavioural studies.

References

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2 Institution of Heating and Ventilating Engineers Guide, 1970, Book B; Section B2
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5 Ventilation requirements for smokers; GW Brundrett; Electricity Council Research Centre; ECRC/M870; Dec 1975

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