Guidance Note EH22 from the Health and Safety Executive

Ventilation of buildings: fresh air requirements

Environmental Hygiene 22 (March 1979)

These Guidance Notes are published under five subject headings: Medical, Environmental Hygiene, Chemical Safety, Plant and Machinery and General.

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INTRODUCTION

Reasons for ventilating buildings

1 The application of section 7 of the Offices, Shops and Railway Premises Act 1963 has given rise to some discussion on the practice of ventilation, and this Guidance Note has been prepared as a technical response to some of the questions that have been raised. There are four reasons for supplying air to buildings. These are:

(a) to satisfy the respiratory needs of the occupants.

(b) to remove body odours and tobacco smoke

(c) to maintain the bodily heat balance

(d) to control airborne contamination.

2 This Guidance Note deals only with the provision of fresh air, i.e. with (a) and (b) above. It does not deal with the thermal environment, i.e. (c) above, even though the maintenance of a suitable thermal environment is probably the most important function of any heating and ventilating system, both because the malaise commonly experienced in badly ventilated rooms is caused, not by impure air, but by the inability of the body to lose the necessary amount of heat, and because, if the system satisfactorily controls the thermal environment, it commonly suffices also for the other requirements. Nor does this Guidance Note deal with the control of airborne contaminants, i.e. (d) above, because these are generally much more prominent in factory conditions since toxic gases and fibrogenic dusts are unlikely to be present in most offices. This aspect of the matter may require attention in kitchens or canteens due to the presence of steam or cooking odours, but it is dealt with by local exhaust ventilation where possible and even though dilution ventilation may play some part the subject will not be discussed here because it has little bearing generally on the amount of fresh air supplied to normal office buildings. This Guidance Note is therefore restricted to the supply of fresh air in order to meet the respiratory requirements of the occupants of the building and to remove both body odours and tobacco smoke. This air is generally a small part of the total air handled by a ventilating or air-conditioning system.

Standard reference books

3 The standard text book on the subject is *Basic Principles of Ventilating and Heating* by Thomas Bedford, and as this is internationally accepted it should always be consulted. It provides a wealth of references in the bibliography which is complete up to 1948 and this Guidance Note can only be based on Bedford's work although some more recent references are included. Other useful books on the subject are the *Guide* published by the Institution of Heating and Ventilating Engineers in London, the *Handbook of Fundamentals* published by the American Society of Heating, Refrigerating and Air-conditioning Engineers in New York and *Industrial Ventilation* published in New York (see References). The current edition of these reference books should always be used.

Fresh air

4 In ordinary engineering practice the term 'fresh air' would mean air from outside the building. It should be as free as possible from any local pollutant and some care should be exercised in choosing the precise position of the inlets. For example, inlets should not be at road level, where they will collect dust and fumes from passing vehicles, nor should they be so placed at higher levels as to collect fumes or grit from chimneys. Since the air of most towns contains quantities of suspended particulate matter it is normal practice to filter the incoming fresh air. Apart from its water vapour content the composition of air is suprisingly constant. Bedford quotes the results of more than 1000 analyses done (in 1937) in a heavily wooded area in New Hampshire, in Boston (Mass.) about 200 feet from a power station burning 35-95 tons of coal a day, and in Baltimore. In only one case did the carbon dioxide content rise to 0.06% by volume but all the other analyses gave volumes between 0.02% and 0.035%. Bedford therefore gives the composition of pure dry air as:

Oxygen	20.94% by volume
Carbon dioxide	0.03% by volume
Nitrogen and other inert gases	79.03% by volume

Artifically purified air

5 The term 'artificially purified air' may be taken to mean air which has been treated chemically or physically so that its composition is similar to that of ordinary outside air and may also include air that has been passed through an air-conditioning plant. The words 'artificial purification' will, therefore, include a variety of processes and

clearly the special measures that must be taken in places like submarines submerged for long periods of time will be unnecessary in most buildings. Generally, therefore, the air in the occupied rooms of a building provided with mechanical ventilating plant will consist of a mixture of air exhaled by the occupants, fresh air and recirculated air. This latter air will have passed through the ventilating plant which will at least have provided some measure of filtration and some adjustment of heat content in winter, and in the more complicated plants may have provided filtration, heat adjustment for winter and summer (i.e. heating or cooling) and humidity adjustment.

Adequate supplies of air

6 It is also necessary to provide adequate quantities of air for any occupied room. The term 'adequate quantities' can only be defined in the context of each individual building and varies with such things as the purposes for which the building is used, the amount of space provided for each of its occupants and whether or not smoking is permitted.

7 It is evident that all buildings will need adequate supplies of fresh air, and that buildings provided with mechanical ventilating systems may need adequate quantities of both fresh air and artifically purified air, although artifically purified air will not be discussed again here. The rest of this Guidance Note will be given to a discussion of those factors which determine what is an adequate quantity of fresh air in a variety of circumstances and, as a matter of convenience, will be divided into an examination of fundamental considerations and good engineering practice. This is because the latter depends entirely on the former.

FUNDAMENTAL CONSIDERATIONS

Theories of ventilation

8 There have been many theories of ventilation. In 1714 Gauger thought that uneven temperatures and lack of ventilation caused the unpleasant sensations that are experienced in badly ventilated rooms. Modern bacteriology has of course shown some infections to be airborne but the composition of the air is no longer regarded as the main cause of the general malaise which results from a lack of ventilation. Lavoisier is quoted by Leblanc (1842) as having attributed the effect to carbonic acid, but Leblanc himself remarked that it was generally attributed to warmth alone. Pettenkofer thought the malaise attributable to the presence of small quantities of organic matter exhaled from the lungs as well as to warmth, or excessive carbon dioxide or lack of oxygen. From 1887 to 1889 Brown-Sequard and d'Arsonval described experiments which seemed to support the theory of toxic materials in expired air because if water, which had been condensed from expired air was injected into animals, they died. They also placed animals in chambers so connected that each one was breathing air exhaled by the others when the animals in the two chambers at the end of the line died. Although these experiments were frequently repeated by different scientists they all failed to corroborate the early results or conclusions. Finally this so-called 'anthropotoxin theory' was disproved by Haldane and Smith (1892). Billings, Mitchell and Bergey (1895) and Hill (1913).

9 In 1907 the Second Report of the Home Office Departmental Committee appointed to enquire into the ventilation of factories and workshops, and in 1909 the Home Office Departmental Committee on humidity and ventilation in cotton weaving sheds, accepted the view that overheating and not the composition of the air was the main problem. In 1914 Hill provided the final proof when he shut seven or eight students in an air-tight chamber of about three cubic metres volume where they remained until the carbon dioxide content rose to between 3% and 4% and that of the oxygen fell to 16% or 17%. The wet bulb thermometer reached 82 degrees F/85 degrees F with the dry bulb thermometer about 2 degrees F higher. They did not notice any diminution of the oxygen content of the air; indeed they tried to light cigarettes and could not understand why their matches went out. Their breathing was slightly deeper on account of the high carbon dioxide content of the air but they suffered no headache. Their condition was relieved by switching on fans. The air caused no discomfort to other students who breathed it while they were outside the chamber, but those inside got no relief when they breathed air from outside the chamber.

10 Bedford comments that these experiments "showed that the speed of movement of the air, as well as its temperature and humidity, exert a profound effect on comfort. Although the purity of the air of occupied rooms is of no small importance, the prime consideration from the standpoint of comfort is that the physical environment shall be suitable."

11 He also quotes a series of experiments by Haldane and Priestley (1905) in which subjects inhaled fresh air and air containing differing amounts of carbon dioxide. It was shown that a concentration of 2% carbon dioxide increased the depth of respiration by no more than 30% and the number of breaths per minute from 14 to 15. The depth of respiration was nearly doubled at 3% carbon dioxide but the number of breaths per minute did not exceed 15. Even with 3% carbon dioxide in the inspired air the concentration of carbon dioxide in the alveolar air remained at the same level as would have resulted from the breathing of normal air so that the carbon dioxide tension in the blood was unchanged.

12 Even when the oxygen content of the air falls to 13% those who breathe the air will not notice the reduction and neither the frequency nor the depth of the respiration will be changed.

13 Bedford comments: "Contrary to what was thought at one time, the changes in the concentration of carbon dioxide which are ordinarily encountered in the air of occupied rooms exert no injurious physiological effect" and "the slight increase in respiration which accompanies an increase in carbon dioxide up to at any rate 2% is hig-

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of smell is quickly fatigued, but even when this odour is not noticed it may make the air somewhat stale. Nevertheless, Flugge (1905) stated that no proof had ever been adduced that such air had any poisonous effects and that any objection to it was only on the grounds of nausea.

16 When a room is ventilated at a uniform rate and a gas is allowed to enter the room, also at a uniform rate, the concentration of the gas will increase exponentially until the system reaches equilibrium. The final concentration will depend on the rates at which the gas enters the room and the ventilating air removes it, and the time to reach the final concentration will vary with the size of the room. If the supply of gas is terminated but the ventilation continued at its constant rate the gas concentration will fall off exponentially. But Yaglou showed that odours sometimes disappeared more quickly than could be explained by this dilution effect of the ventilating air, and that with a constant ventilating rate the speed of disappearance of the odour increased as the amount of space per person increased. He also noticed that odours disappeared quickly from virtually air-tight rooms after the occupants had left them. The amount of space per person therefore influences the rate of disappearance of odours quite apart from the volume of fresh air supplied per person per hour. Yaglou also noticed that the efficiency of odour removal decreased as the ventilating rate was increased, because with high rates of ventilation some of the fresh air leaves the room without proper mixing and so makes no improvement in the condition of the residual air.

Fresh air supplies

17 Many standards have been suggested over the last hundred years or so, varying from 5 to 50 cubic feet of fresh air per person per minute (300-3000 cubic feet of fresh air per person per hour), but is to be remembered that, apart from the matters already discussed, the standard suggested will also vary with the personal hygiene of the occupants as well as with the sensitivity of the observer.

20 It is generally assumed that the average person produces 0.6 cubic feet of carbon dioxide per hour so that a concentration of 2 parts in 10,000 means a fresh supply of 50 cubic feet per person per minute (3,000 cubic feet of fresh air per person per hour). But De Chaumont stated that odours became just perceptible when the carbon dioxide from respiration was 4 parts in 10,000, or when the fresh air supply was 25 cubic feet per person per minute (1500 cubic feet of fresh air per person per hour).

21 De Chaumont's very high standard of 50 cubic feet of fresh air per person per minute (3000 cubic feet of fresh air per person per hour) has not been adopted but his standard of 25 cubic feet of fresh air per person per minute (1500 cubic feet of fresh air per person per hour) is close to Roscoe's proposal of 20 cubic feet of fresh air per person per minute (1200 cubic feet of fresh air per person per hour). It is to be noticed that De Chaumont makes no reference to the cubic space allowed per person. Yaglou and his co-workers investigated the problem further in 1936, once again taking the absence of odour as the criterion of satisfactory ventilation. These workers found that the quantity of fresh air needed varied with the number of persons in the room (i.e. with the cubic space allowed to each person) and with their standards of personal hygiene. The suggested standards are given in Table 1 page 5).

22 Bedford comments: "The requirements vary for different types of occupant, but as a broad generalisation it can be said that for most ordinary conditions an air supply of 17 to 20 cubic feet per minute per person will give satisfactory results." He adds that "the fresh air supplies mentioned represent minimum requirements. The maximum ventilation that can be achieved with comfort, when regard is paid to necessary limitations such as those imposed by shortage or cost of fuel, is desirable".

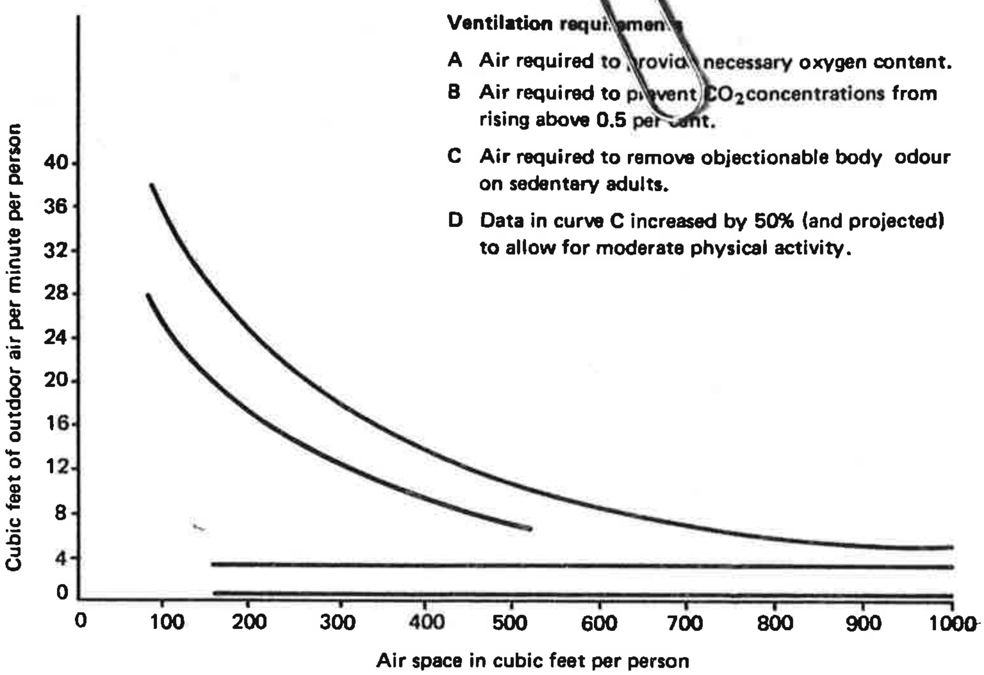

Fig.1 (*Industrial ventilation* - Ref. 4)

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Engineering practice

23 Good engineering practice is based on the physiological and scientific results outlined in the preceding paragraphs, and one method of estimating the fresh air requirements is set out in Figure 1 which shows curves taken from *Industrial Ventilation,* published by the American Conference of Governmental and Industrial Hygienists. Curve A shows the small amount of air needed to supply oxygen and Curve B, that needed to keep the carbon dioxide level below 0.5 per cent, this figure being selected because it is the threshold limit value *for this gas. Curve C shows the amount of fresh air needed to control odours from sedentary adults and the working Curve D increased this by 50%, so that the fresh air volume given by Curve D is sufficient to meet all requirements.

24 It is noticeable that as little as one cubic foot of fresh air per person per minute will meet the oxygen requirement and about 3.5 cubic feet of fresh air per person per minute the carbon dioxide requirement. In fact the figure of one cubic foot may be used in closed spaces in very special circumstances, but it has no relationship to ordinary buildings.

25 At the statutory minimum space requirement of 400 cubic feet per person, the graph indicates 9 cubic feet of fresh air per person per minute (540 cubic feet per person per hour) to deal with oxygen supply, the carbon dioxide content and odour removal. This is increased by 50% to allow for some physical activity giving a recommended value of 14 cubic feet of fresh air per person per minute (840 cubic feet per person per hour). This figure is in excess of the indications for Yaglou's Table (Table 1, page 5). where he suggests 12 cubic feet of fresh air per person per minute if the air space is only 300 cubic feet or 7 cubic feet per person per minute if the space is 500 cubic feet. Presumably about 10 cubic feet of fresh air per person per minute (600 cubic feet per person per hour) would meet the statutory space requirement of 400 cubic feet if Yaglou's Table were used.

26 Table 3 (page 7) gives the American recommendations (Ref. 2) for outdoor air, i.e. fresh air, to be supplied to a wide range of buildings with modifications to allow for smoking in some instances. In each case a recommended and a minimum amount of fresh air per person per minute is given or a minimum volume of fresh air per square foot of floor per minute.

27 Table 2 (page 6) gives the figures to which United Kingdom ventilating engineers work (Ref. 3). Here again recommended and minimum quantities of fresh air per person per minute and per minute per square foot of floor are given, with an added note that calculations on the former basis should be checked against corresponding calculations on the latter basis. It is also to be noticed that a further check is added in the last column to deal with rooms with a ceiling height of about 10 feet. For example, the figure of 0.1 cubic feet of fresh air per minute per square foot of floor may well be adequate for the older type of departmental stores with large high rooms, wide walkways and small showcases but quite inadequate for modern self-service stores with low ceilings, narrow passageways, racks full of goods from floor to ceiling and crowded conditions. In these circumstances it has already been suggested that the minimum amount of fresh air per square foot of floor should be of the order of 0.6 cubic feet per minute.

* The threshold limit value (TLV) refers to airborne concentrations of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. See *Threshold Limit Values* Guidance Note E15/78 (obtainable from HMSO, Price 30p).

CONCLUSION

28 The necessary volume of fresh air per person per minute varies considerably with the circumstances. These volumes can be determined from the fundamental considerations already discussed. They have also been set out in some detail as recommended and minimum quantities in the references quoted.

29 It must not be forgotten that quite apart from the fresh air supplied there is an infiltration of air into a building which may easily double the amount of fresh air actually available inside although this is omitted from the calculations.

30 Nevertheless in general the recommended figure is to be preferred to the minimum figure as given in engineering reference books, and the quantity of fresh air supplied should never fall below 10 cubic feet (0.28 cubic metres) per person per minute in ordinary normal buildings.

REFERENCES

1 Bedford, Thomas, *Basic Principles of Heating and Ventilation,* H K Lewis & Co Ltd, London.

2 *Handbook of Fundamentals,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, 345 East 47th Street, New York, NY 10017.

3 *Guide,* Institution of Heating and Ventilating Engineers, 49 Cadogan Square, London, SW1.

4 *Industrial Ventilation,* American Conference of Governmental Industrial Hygienists, PO Box 453, Lansing, Mitchigan, 48902, USA.

Table 1

Minimum values of outdoor air requirements (Yaglou et al 1936)

Type of occupants	Air space per person (cubic feet)	Fresh air supply required (cubic feet per person per minute)
Sedentary adults of average socio-economic status	100	25
	200	16
	300	12
	500	7
Labourers	200	23
School children of average class	100	29
	200	21
	300	17
	500	11
School children of poor class	200	38
School children of better class	200	18

Table 2 Fresh air quantities for fully air-conditioned rooms

(see *Guide*, Reference 3)

Application	Smoking	Cubic feet per minute per person		Cubic feet per minute per square foot of floor	Air change for 10ft room height
		Recommended	Minimum		
(1)	(2)	(3)	(4)	(5)	(6)
Banking spaces	Some	10	7½	0.25	1.5
Board rooms . .	Heavy	50	30	0.5	9.0
Cocktail bars	Heavy	30	25	1.25	7.5
Department stores	Some	10	7½	0.1	0.6
Factories	None	10	7½	0.2	1.2
Hospital, operating rooms	None	–	–	2.0	12.0
" private rooms	–	30	25	0.33	2.0
" wards	–	20	15	0.4	2.4
Hotel rooms	Heavy	30	25	0.33	2.0
Laboratories	Some	20	15	0.25	1.5
Offices, general	Some	15	10	0.25	1.5
" private	None	25	15	0.25	1.5
" private	Heavy	30	25	0.25	1.5
Resistances	Some	20	15	0.25	–
Restaurant, cafeteria	Heavy	12	10	0.75	4.5
" general	Heavy	15	12	0.75	4.5
Theatres	Some	17	17	–	–

Notes

(i) If column (3) or (4) is used to determine fresh air quantity then the air changes rate should be checked to ensure that it does not differ greatly from the figures of column (6)

(ii) The design engineer should check that local regulations or bye-laws do not call for figures in excess of the above.

(iii) All inlet air or operating theatres should be fresh.

(iv) The amounts given for operating theatres and laboratories should be considered as minimum figures.

Table 3 Outdoor air requirements[a]

(See *Handbook of Fundamentals* Reference 2)

Application	Smoking	Cubic feet per minute per person[b]		Cubic feet per minute per square foot of floor[b]
		Recommended	Minimum[c]	Minimum[c]
Apartment				
Average	Some	20	10	–
De Luxe	Some	20	10	–
Banking space	Occasional	10	7½	–
Barber shops	Considerable	15	10	–
Beauty parlours	Occasional	10	7½	–
Brokers' board rooms	Very heavy	50	20	–
Cocktail bars	–	40	25	–
Corridors (supply or exhaust)	–	–	–	0.25
Department stores	None	7½	5	0.05
Directors' rooms	Extreme	50	30	–
Drug stores[e]	Considerable	10	7½	–
Factories[d,f]	None	10	7½	0.10
Five and ten cent stores	None	7½	5	–
Funeral parlours	None	10	7½	–
Garages[d]	–	–	–	1.0
Hospitals				
Operating rooms[f,g]	None	–	–	2.0
Private rooms	None	30	25	0.33
Wards	None	20	10	–
Hotel rooms	Heavy	30	25	0.33
Kitchens				
Restaurant	–	–	–	4.0
Residence	–	–	–	2.0
Laboratories[c]	Some	20	15	–
Meeting rooms	Very heavy	50	30	1.25
Offices				
General	Some	15	10	0.25
Private	None	25	15	0.25
Private	Considerable	30	25	0.25
Restaurants				
Cafeteria[e]	Considerable	12	10	–
Dining room[e]	Considerable	15	12	–
Schoolrooms[d]	None	–	–	–
Shop, retail	None	10	7½	–
Theatre[d]	None	7½	5	–
Theatre	Some	15	10	–
Toilets[d] (exhaust)	–	–	–	2.0

(a) Taken from present-day practice.
(b) This is contaminant-free air.
(c) When minimum is used, take the larger of the two.
(d) See local codes which may govern.
(e) May be governed by exhaust.
(f) May be governed by special sources of contamination or local codes.
(g) All outside air recommended to overcome explosion hazard of anaesthetics.

FURTHER INFORMATION

This Guidance Note is produced by the Health and Safety Executive. Further advice on this or any other publications produced by the Executive is obtainable from Baynards House, 1 Chepstow Place, London W2 4TF, or from Area Offices of the HSE.

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