REQUIREMENTS FOR VENTILATION

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Ventilation criteria are viewed in terms of both the building and the occupants. Moisture control is necessary to preserve the building fabric. The occupants have additional sensitivity to chemical contamination such as odours and cigarette smoke. Criteria can be expressed in minimum acceptable concentrations for health reasons, or even lower concentrations for comfort. The ventilation needed to meet these criteria is derived from a knowledge of the generation rate of the pollutant, the effectiveness of ventilation mixing, the characteristics of the fresh air supplied, and the temperature of the occupied room.

INTRODUCTION

Contaminants can build up inside sealed buildings to create discomfort for the occupants and, in the long term, can both affect their health and spoil the integrity of the building fabric. Fresh air is therefore necessary to dilute these contaminants to an acceptable level. This paper reviews the contaminants individually and then, in terms of overall design, collectively.

CONTAMINANTS

Carbon dioxide

Breathing is controlled primarily by the carbon dioxide concentration in the lungs (Bell et al. (1)). When inspired air contains approximately 2% by volume of carbon dioxide, then the depth of breathing increases. When the concentration reaches 3-5% by volume, there is a conscious need for increased respiratory effort and the breathing rate increases and the atmosphere becomes objectionable. Concentrations over 6% are dangerous. The maximum allowable concentration for 8 hour exposures for healthy adults is 0.5% by volume.

The usual source of carbon dioxide is the occupants themselves. The generation rate is directly proportional to the number of people and their activity. The ventilation needed for carbon dioxide dilution is illustrated in Table 1 (BS 5925: 1980 (2)).

TABLE 1 - Outdoor air requirements for respiration (BS 5925: 1980)

Activity	Metabolic rate (watts)	Requirements for oxygen (16.3% O_2 in expired air) (m^3/h)	Requirements for carbon dioxide at 0.5% by volume (m^3/h)
Seated quietly	100	0.36	2.9
Light work	160-320	0.7-1.1	4.7-9.4
Moderate work	320-480	1.1-1.3	9.4-14
Heavy work	480-650	1.8-2.5	14-19
Very heavy work	650-800	2.5-3.2	19-23

Flueless heating appliances are also a source of carbon dioxide. A 3 kW paraffin heater is equivalent to 20-30 people in the room (BRE Digest No. 206 (3)).

Odours

Healthy, clean people give off odours even immediately after a bath (Yaglou et al. (4)). Such odours are not known to be harmful but can be unpleasant and diminish appetite. Odour generation is proportional to the size of the adult (Lehmberg et al. (5)) and the time elapsed since the last bath. Children younger than 14 years old are more powerful generators than adults (Figure 1).

Odour concentration cannot always be measured chemically and so empirical ventilation rates are prescribed. An unusual feature of body odours which distinguishes them from simple chemical odours is that acceptability is influenced both by concentration and by personal space. Much more fresh air is needed as the personal space declines (Figure 2).

Empirical data suggests a minimum air extract rate from the W.C. should be 20 cu. metres per hour (BRE Digest 170 (6)).

Smoking

In normal cigarette smoking, more tobacco burns during the smoulder period and escapes to the room than during the inhaling period, when the smoker absorbs the combustion products himself. This sidestream smoke requires dilution (Brundrett (7)).

While the tobacco type, its treatment, the cigarette size and smoking pattern are very varied, an approximate value of $20m^3$ of fresh air is needed to dilute the sidestream smoke from a cigarette to an acceptable air quality. Since the average British smoker consumes 1.3 cigarettes an hour, then a fresh air allowance of 26 m^3/h is needed for each smoker. In small offices, the probability of an office containing mainly smokers is high and so this fresh air is needed for each occupant. In large offices of 50-100 occupants, it can be assumed that the population in the office will reflect the normal adult population, of which half smoke. The ventilation rate can therefore be halved, since only half the occupants will be expected to smoke (Halfpenny & Starrett (8)). If the cigarette consumption is known to be much lower or much higher, then appropriate changes in the ventilation rate will be necessary. Experience suggests that the values given in Table 2 are adequate for Britain (CIBS (9)).

TABLE 2 - Ventilation to dilute cigarette smoke

Smoking	Space	Minimum outdoor air m^3/h per person	Recommended outdoor air m^3/h per person
some	open plan office	18	29
heavy	private offices	29	43
very heavy	board rooms	65	90

Lower quantities of fresh air introduce irritation to the eyes and respiratory passages. When this occurs, there is the risk that the maximum permitted concentration of acrolein has been exceeded (Figure 3).

Moisture

Moisture has two kinds of effect. The first is related to relative humidity, while the second is related to vapour pressure.

Organic materials such as wool, paper, cotton and leather, absorb moisture as a function of the relative humidity in the atmosphere (Hearle & Peters (10)). If this relative humidity becomes low, then fabrics become less flexible and less electrically conducting. Electrostatic shocks can be expected from walking on carpets when the relative humidity falls below 40% (Brundrett (11)). When the relative humidities rise above 70%, then fabrics become damp to the touch (Lake & Lloyd-Hughes (12)), mould spores can develop (Brundrett & Onions (13)), and house mites thrive (Cunnington (14)). Unfortunately, the relative humidities involved are those immediately adjacent to the fabric rather than the bulk air in the centre of the room. This means, for example, that wallpaper on a cold wall could have very high relative humidities immediately adjacent to it, while the values in the room centre are low. In practice, moisture problems are avoided if the bulk air in the room does not rise above 70% relative humidity (HMSO (15)).

Physiological factors such as dry throats, cracking skin, and sultriness, depend more upon the absolute water vapour pressure. While work is limited in this area, illustrations of these relationships are given in Figure 4 (Brundrett (16)). The generation rate of moisture within the house is summarised in Table 3 according to activity, and is typically 7 kg a day unless clothes are dried in the house, when this value is doubled (Loudon (17)). Ventilation requirements needed to prevent excessive relative humidity depend on both the moisture generation rate in the house and the moisture content in the outdoor air. The moisture in the outdoor air depends in turn upon the outdoor air temperature (Figure 5) (Heap (18)). This means that for a constant moisture generation rate in the house, the ventilation will need to increase progressively with outdoor temperature to maintain a chosen relative humidity (Figure 6). Local extraction of moisture vapour at source, such as with a cooker hood, or any form of dehumidification, could significantly reduce this ventilation requirement (Brundrett (19)).

TABLE 3 - Moisture generation rates in five person houses (Loudon 1971)

Activity	Generation rate
Moisture from the occupants (perspiration and respiration)	1.7 kg/day
Clothes washing	0.5 kg/day
Clothes drying	5 kg/day
Cooking (gas)	3 kg/day
Baths and washing	1 kg/day
Daily average	7.2 kg/day 14.4 kg on washday

Radon

Minute traces of uranium are present in most rocks, soils and common building materials. Uranium is radioactive and decays down to a stable lead isotope. One of the products of this chain is the gas radon. Radon has a half-life of 3.8 days, which is sufficient for it to diffuse from building materials and from the sub-soil underneath a house into the buildings. The radon gas decomposes into four short-lived daughters, which can be inhaled. Inhaled daughters can decay within the lung and could increase the incidence of lung cancer (Davies (20), Doll & Hill (21)). The health risk is proportional to the radon concentration and the time exposed to it (Table 4). Present evidence suggests that the minimum ventilation rate for a house in Britain should be 0.2 air changes an hour.

TABLE 4 - Predicted lung cancer incidence in the UK due to environmental $222R_n$ daughter concentrations as the mean winter (7 months) ventilation rate is reduced: the summer (5 months) mean ventilation rate is assumed to be constant at 2 air changes per hour

Winter ventilation rate h^{-1}	Mean population exposure WLM y^{-1}	Lung cancer incidence predicted per 10^6 population per year	Number of cigarettes smoked per week to give the same lung cancer incidence (Derived from Ref. 20)
0.8	0.15	15	1.5
0.5	0.22	22	2.2
0.4	0.28	28	2.8
0.3	0.38	38	3.8
0.2	0.58	58	5.8
0.1	1.15	115	11.5

VENTILATION REQUIREMENTS FOR DESIGN

The four design factors are:

1. extract contaminants at source
2. ventilate for the worst pollutant
3. avoid by-passing of the supply and extract air
4. control the flow route

When the sources of pollution are known, the first design requirement is to remove as much as possible at source. Once that is done the generation rates of the pollutants into the room can be estimated. For all practical purposes, the common pollutants can be considered to be independent of each other. The ventilation needed for each pollutant should then be calculated and the highest ventilation rate chosen. When air is supplied at low rates, it slowly but intimately mixes with the room air. The relative positions of the inlet and outlet grilles are not very important. However, at high ventilation rates, some correction is needed for the inefficiency of the air mixing. The chances of short-circuiting increase with the higher ventilation rates and more care is needed in positioning and distributing the inlet and extract air (Yaglou & Witheridge (22)).

Finally, while in general it is desirable to provide each room with fresh air, exceptions can be made for buildings such as houses. The conventional house has two types of rooms, clean residential rooms and service rooms. The residential rooms, which include living rooms and bedrooms, can be supplied with fresh air to ensure pleasant conditions during the long periods these rooms are occupied. However, the service rooms such as kitchen, bathroom and toilet, are occupied for shorter periods and it is the traditional approach in mechanically ventilated houses to supply the fresh air to the clean rooms and extract the same air from the kitchen and other service areas. Routing the air this way saves much ventilation.

FUTURE NEEDS

As the importance of ventilation becomes recognised, we will need to strengthen five weaknesses. The first is to refine the ventilation criteria. Most work has concentrated on the adult population and for eight hour exposure as in a working day. Buildings can contain children, the elderly and the infirm, and often for continuous occupancy. More research is needed to assess suitable criteria for these common circumstances.

The second is the need for simple sensors which will guide the occupants of the building on whether or not they have gross under- or over-ventilation. The need for such instrumentation is strongest for those pollutants such as radon or carbon monoxide, or carbon dioxide, which the occupants themselves cannot sense. However, low cost detection of the more recognised pollutants, such as cigarette smoke or moisture, could be valuable as the starting point for more advanced energy saving controlled ventilation schemes.

The third is an educational exercise to show the importance of removing contaminants at source. This includes cooker hoods venting to the outside to remove moisture and odours, and also proper use of venting kits for appliances such as tumble dryers. It also includes the dangers of unflued heaters.

The fourth is recognition of the importance of the ventilation route. In many circumstances, the fresh air can be designed to serve two purposes. In a house, for example, if fresh air is introduced into the living room to dilute body odours, the same air can be extracted from the kitchen, taking with it the added moisture and cooking smells.

The fifth is the development of alternative methods of lowering the pollution concentration. Research is already exploring deodorising techniques to remove or destroy malodorants and advanced dehumidification techniques to solve moisture problems.

CONCLUSION

Ventilation is necessary to dilute common contaminants to acceptable concentrations for health and comfort, and to protect buildings.

The ventilation requirements are mainly a function of the generation rate of the pollutant and the maximum allowable concentration. Unoccupied buildings need a minimum ventilation rate to prevent a build-up of radon. This is mainly a function of the building materials. The minimum for occupied buildings depends upon the carbon dioxide generation. This generation is directly related to activity level. Cigarette smoke is proportional to the cigarette consumption although the criterion of acceptability varies from the relatively sensitive one of a visitor, to the much less sensitive one of a smoker. Body odours are unusual in being related not only to the elapsed time since the last bath, but also to the allocated volume of personal space. Designing for moisture control is the most difficult, since it is a complex function, not only of the outdoor vapour pressure and the indoor moisture generation rate and location, but also of the temperatures of individual parts of the rooms, which should remain above the air dew point.

Further work is needed on ventilation routes so that fresh air can be introduced to the living rooms and extracted from the service rooms, which are usually more contaminated. Separate fresh air supply is then not necessary in the service room. The air flow is then in opposition to the contaminant gradient. More attention must be paid to local contamination control. This includes cooker hoods and vented clothes dryers to prevent moisture and odours escaping into the room. It also includes dehumidifiers, which can not only reduce the ventilation requirement but also transduce latent heat into sensible heat.

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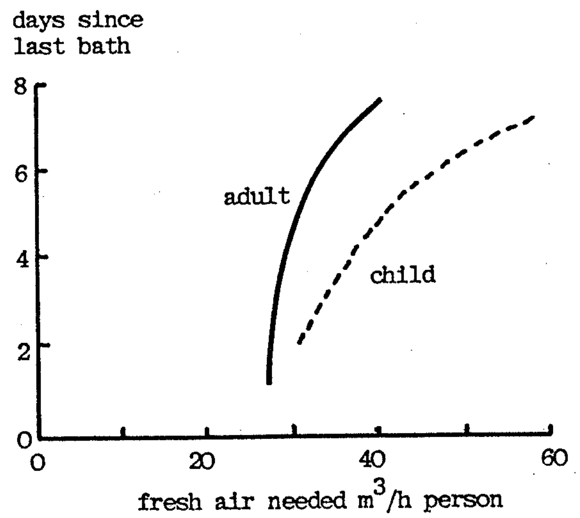

Figure 1 Fresh air needed for acceptable body odour

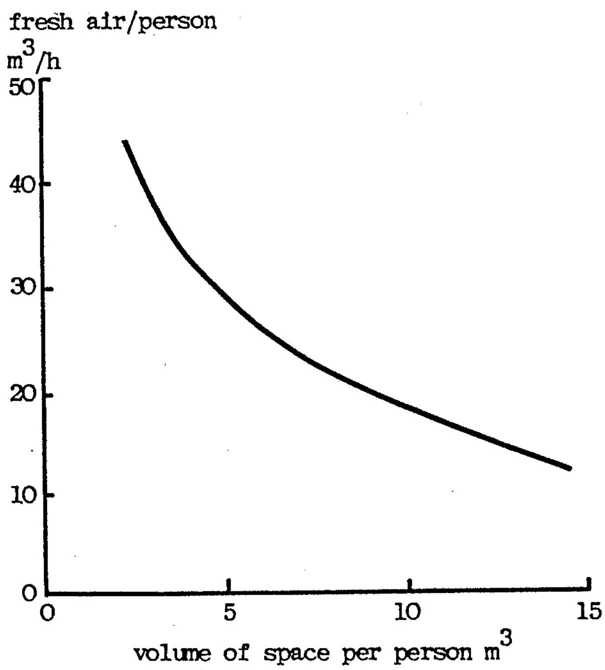

Figure 2 Fresh air needed for acceptable body odour as a function of personal space

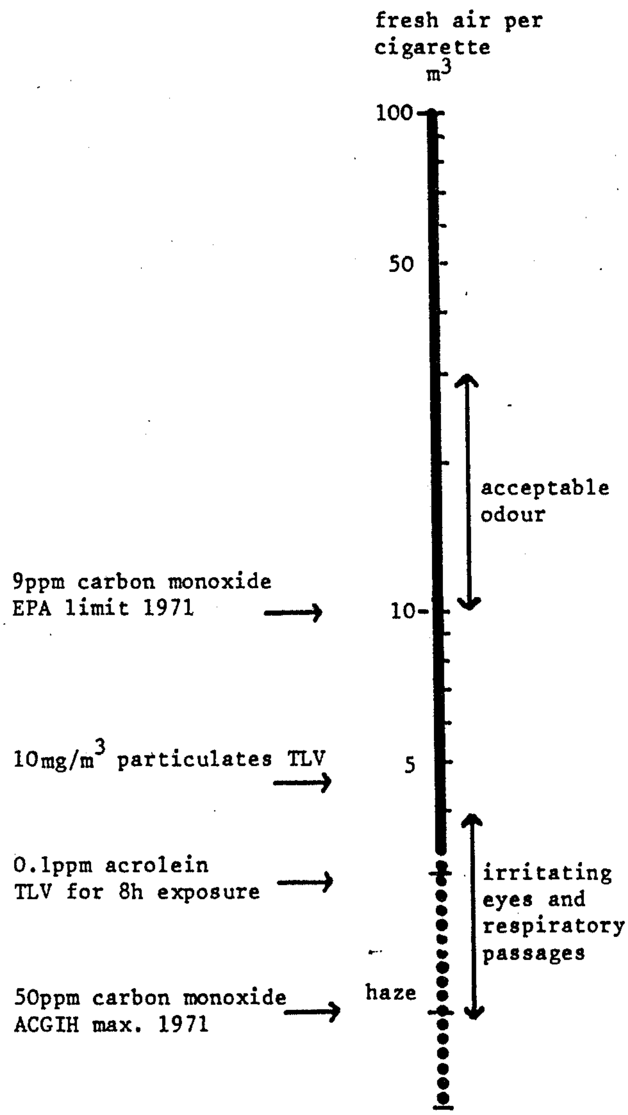

Figure 3 Fresh air needed to dilute cigarette smoke

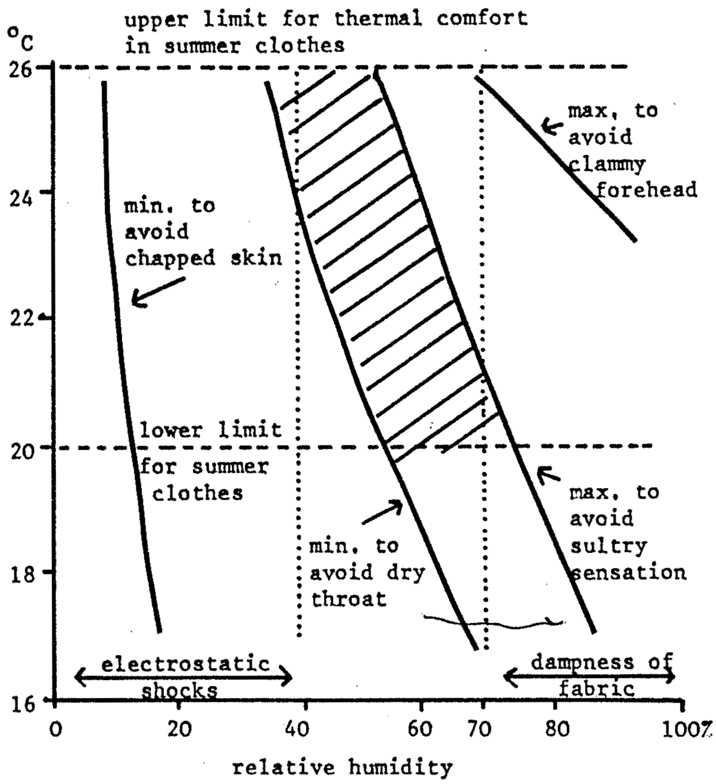

Figure 4 Comfort zone for sedentary people (shown hatched)

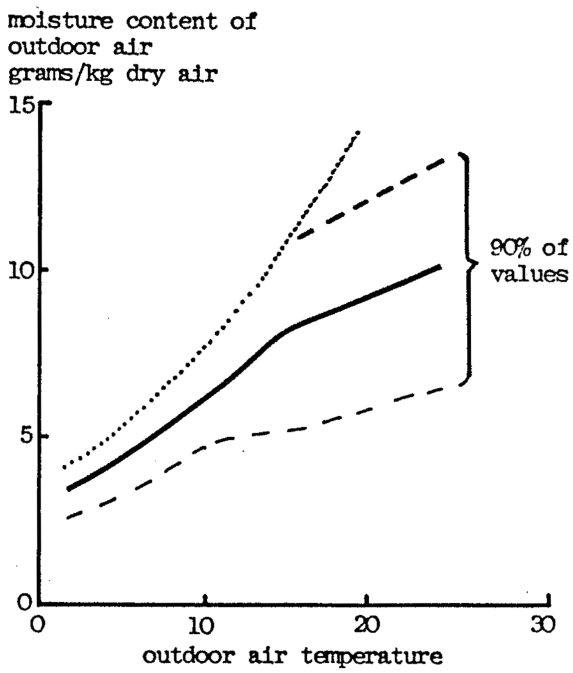

Figure 5 The relation between moisture content and outdoor air temperature

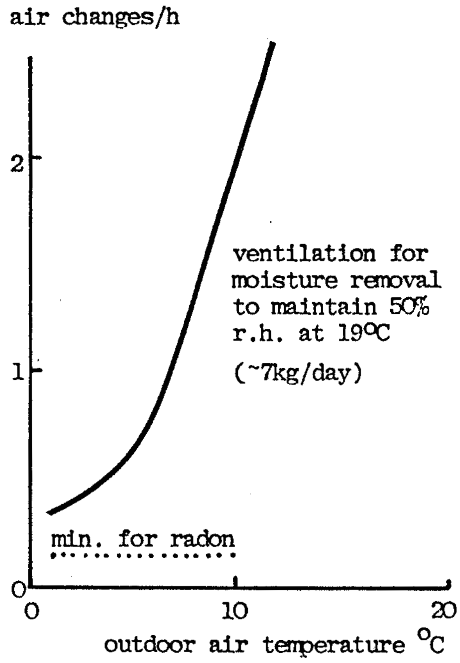

Figure 6 Ventilation requirements for domestic moisture control and radon in the house