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Housing, air hygiene and animal health

Summary
A knowledge of air hygiene is fundamental to the design of livestock buildings because chronic exposure to airborne pollutants may render housed animals more susceptible to infections of the respiratory tract. At present, some guidelines to good air hygiene exist but more rules are needed.

Introduction

One of the most important considerations in the design of animal houses is the health of the occupants. The architect of a successful building must therefore have an interest in, and a knowledge of, hygiene, i.e. "a system of principles or rules for preserving and promoting health" (Shorter Oxford Dictionary). Attention to good hygiene has a somewhat 19th century ring to it and can be criticised for lack of specificity; many infectious diseases are better controlled by means such as vaccination or by a policy of eradication (Webster, 1982). Nevertheless, there remain many "environmental" diseases of complex aetiology which are not at present amenable to either solution. Poor hygiene, possibly the result of faulty building design, is often implicated in the causes of these diseases. A proper definition of poor hygiene and attention to those details and features which encourage good hygiene are essential steps in the design of a sound building.

Hygiene, in the context of animal housing, is concerned with the survival and spread of both pathogenic and non-pathogenic microorganisms; the harmful effects of airborne pollutants such as dust and noxious gases; and, indirectly, the fate of such foreign agents after entry into the body. Rules for good hygiene might include

(1) tolerable levels for airborne and surface contaminants specified in terms of concentration or level and duration of exposure;

(2) maximum stocking density and herd size within an airspace and/or pen;

(3) minimum distances for separation of buildings on a farm and between farms of like type, and

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Fig 1 *Loose-housed veal calves*

(4) procedures for cleaning and disinfection following depopulation.

Clearly the content and relative importance of these rules must be laid down according to the age, class and system of husbandry of the livestock involved.

In general the physical environment of an animal house can affect an animal's health by

(i) altering the animal's systemic resistance to infection;

(ii) increasing the magnitude of the challenge from infectious microorganisms or allergenic particles by enhancing their survival and spread, and

(iii) changing the microbes' rate of deposition within and clearance from the animal's body surfaces such as the respiratory tract (Webster, 1982).

Whether or not challenge proceeds to disease depends on the relative balance between these mechanisms.

For many years veterinarians and animal scientists have speculated on the association between poor air hygiene and respiratory diseases of housed livestock. In the United Kingdom their concern is valid because respiratory diseases are a major cause of economic loss. The purpose of this review, therefore, is to consider for housed livestock what principles and rules of air hygiene are established at present and in which areas guidelines have yet to be devised.

The animal's encounter with airborne pollutants

The atmosphere in most animal houses is heavily polluted with airborne dusts, noxious gases and microbial aerosols which are produced by the animals themselves, the bedding and feed. The potentially harmful effects of such atmospheres on the health and performance of the livestock have been the concern of animal scientists and farmers for many years (e.g. Curtis and Drummond, 1982). In practice, both the nature of the environmental challenge and the animal's response are extremely complex and until recent years few studies had attempted a sufficient description of either. At present, therefore, our knowledge is very incomplete.

Exposure to airborne pollutants can be either short-term, lasting up to one or two hours, or long-term (i.e. weeks or months). Acute exposures typically arise during the emptying of underground manure stores (Nordström and McQuitty, 1976; Feilden, 1982) or re-bedding (Cricklow, Yoshida and Wallace, 1980). The effects of acute exposures include death due to toxaemia or an acute allergic response in the case of sensitised animals. During chronic exposure to a pollutant an animal may become more susceptible to infection by a respiratory pathogen. This response is superimposed on the direct effects of the pathogen and depends on the dose of the pollutant and its timing in relation to the microbial challenge (Holt and Keast, 1977).

Factors affecting course of infection

The major factors which are capable of affecting the course of a respiratory infection during exposure to an airborne pollutant are the duration of exposure, the size, toxicity and concentration of the pollutant; the infectious microorganism, its dosage and physical characteristics, such as size and composition of suspending fluid; and the immune status of the animal. Once inhaled, the hazard that a pollutant presents to an animal depends on the site of deposition, the length of stay at the site and the pathways and rates of clearance. The site of deposition is governed mainly by the particle's aerodynamic diameter, in the case of aerosols, while the rates are influenced by the physical deposition mechanism, the anatomy of the airways and the characteristics of the breathing region (Morrow, 1974). Rates of clearance are far more rapid in the ciliated nasal passages and the tracheobronchial tree than the pulmonary portion (Lippman, Yeates and Albert, 1980). A model of airborne pollution must, therefore, distinguish between the functions and clearance mechanisms of these different regions.

The lung's response to provocation by an inhaled particle depends greatly on the site of deposition. In aerobiological studies the respiratory tract is usually divided into three regions, the nasopharyngeal, the tracheobronchial and the pulmonary, based upon anatomical features and upon deposition and clearance mechanisms (Phalen, 1984). The injuries caused by different pollutants also vary between the regions. Within the nasopharynx a common symptom is rhinitis, while the reactions of the tracheobronchial region include bronchoconstriction, hypersecretion of mucous, oedema of the bronchial walls and bronchial infection. Inflammation, oedema, fibrosis and cancer can all be caused in the pulmonary portion.

Once the lungs have been damaged by an airborne pollutant their clearance mechanisms may be impaired. In the particular case of calf pneumonia, Pritchard (1980) suggests that the impairment may result from "cilial loss due to viruses or mycoplasma, bacterial endotoxin, noxious gases such as ammonia or to overburden of the mucociliary escalator by aerial bacteria, fungi or dust." If this is true then reductions in the level of airborne pollutants within calf houses should diminish the incidence or the severity of calf pneumonia. Indeed, in a subsequent study, Pritchard et al (1981) produced evidence to show that filtration of recirculated air within a veal house did lower both the incidence and severity of respiratory disease. These benefits were attributed to the smaller burden of airborne dust and bacteria, since the concentrations of both were reduced.

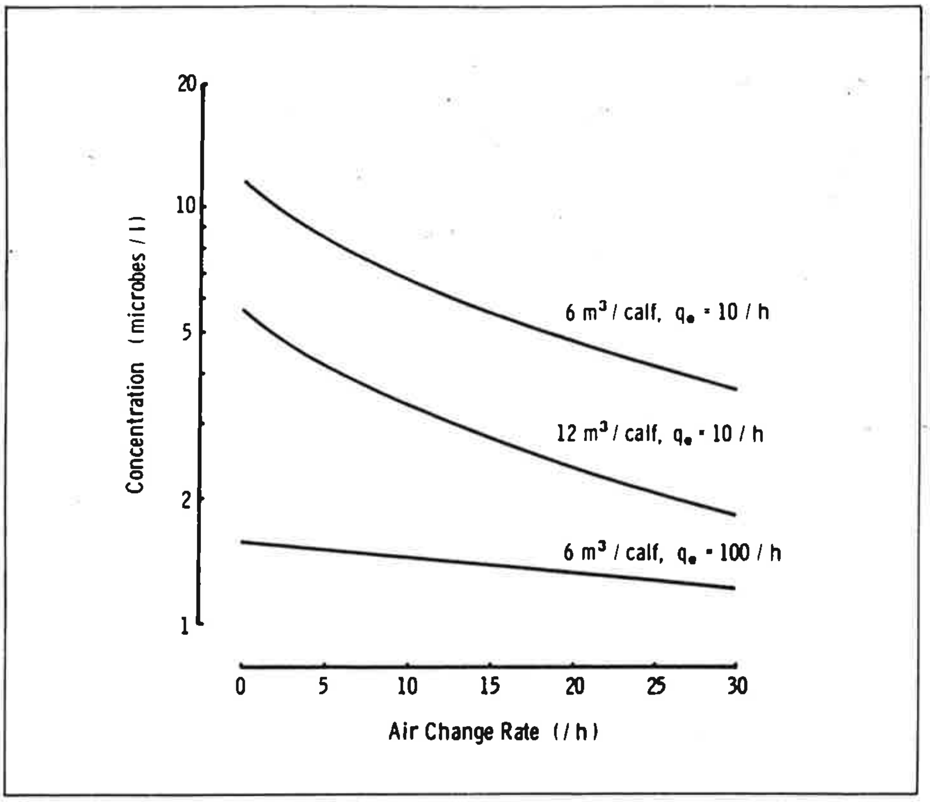

Fig 2 *Minimum ventilation rates for broilers using four criteria. Building details: volume = 4000 m³; floor area = 1440m²; ridge height = 6m; eaves height = 2m; overall U value = 0.5 W m⁻² °C⁻¹; temperature = 31.5°C at 1d reducing by 0.5 °C d⁻¹ to 21°C at 22d. Ambient conditions: CO_2 = 0.034%; NH_3 = 0 ppm; moisture content = 4.85 g m⁻³; air temperature = 0°C. Rates for the building heat balance (temp = target) are only shown after 22d and are calculated without allowance for supplementary heating. Published by kind permission of the Editor, The Veterinary Record.*

Effects of specific airborne pollutants

The most common noxious gases in livestock buildings are ammonia, hydrogen sulphide, methane and carbon dioxide, of which the first two are classified as irritants and the last two are simple asphyxiants. Although there have been some studies of the direct effects of acute and chronic exposure to these gases, far more is known about gases which are less relevant to agriculture, such as ozone, nitrous oxide and sulphur dioxide. Acute poisoning of housed cows and pigs by ammonia and hydrogen sulphide is often associated with agitation of aged slurry (Nordstrom and McQuitty, 1976). The lethal concentration of hydrogen sulphide for pigs is about 400 ppm (O'Donoghue, 1961). Reports of the effects of chronic exposure to ammonia are contrary. Some authors (Stombaugh et al, 1969) found a depressant effect of high concentrations (100-150 ppm) while others (Curtis et al, 1974) did not, except when 50 ppm of ammonia was combined with a heavy dust burden (300 mg/m³). As with aerosols, the absorption of gases by the lung varies between regions: gases which are highly water soluble are absorbed in the upper airways, while those which are water insoluble penetrate to the pulmonary region (Phalen, 1984). At present guidelines for the critial levels of gases have not been established for farm animals and must be based mainly on the human threshold limiting values (TLV). These, however, suppose a five-day working week; animals must endure their polluted atmospheres continuously and may have to face two or more pollutants simultaneously. The current 'safe' limits can be taken as 5, 20, 300 and 3000 ppm for H_2S, NH_3, CH_4 and CO_2 respectively (Bruce, 1981).

Dust

The major sources of dust in animal houses are the animals themselves, in the form of skin squames, the litter or bedding and the feed. Inhalation of dust can modify both non-specific and specific immune functions in the lung according to the nature of the dust and to the animal's previous experience (Holt and Keast, 1977). Furthermore, dust may also act as a vector of disease, e.g. Marek's disease of poultry (Jurajda and Klimes, 1970). The present TLV for human exposure to inert dust is 10 mg/m³ and peak dust burdens exceeding this level have been recorded during rebedding, feeding and cleaning in animal houses (Cermak and Ross, 1978). What is needed for good air hygiene is TLV's for dusts of specific origins, which are related to respiratory disease either directly or indirectly.

Aerial microbial flora

Less is known about the aerial microbial flora of the air of livestock buildings. Here it is important to distinguish between potentially pathogenic microbes such as *Pasteurella haemolytica,* which is considered to be an opportunistic pathogen in calf pneumonia, and the majority of airborne microbes which are non-pathogens but may nevertheless embarrass the respiratory tract (Pritchard, 1980). The origins of airborne microbes are probably the same as inert dust but there is one important characteristic which distinguishes these two pollutants, namely the viability of the microbes. Once airborne, the lifetime of a microorganism depends greatly on climate with half-lives varying from a few seconds to many hours (Donaldson and Ferris, 1976; Müller et al, 1981). In general the effects are complex and vary greatly between species of viruses, bacteria, mycoplasmas or other microorganisms (Donaldson, 1978). Furthermore, no one component of the physical environment such as dry bulb temperature or relative humidity adequately describes the climatic stress on the airborne microbe (Wathes et al, 1984). While there may be particular climates which are unfavourable to an individual microbe's survival, these will probably differ from that for a heterogeneous cloud of microorganisms such as exists within an animal house. There is insufficient knowledge at present to specify the climate which minimises the concentration of a mixture of airborne microorganisms. In the case of specific pathogens, such as Respiratory Syncitial Virus (RSV) of cattle, practically nothing is known.

Implications for building design

The features of a building which are affected by the requirements for air hygiene include the minimum ventilation rate, cubic capacity, building separation and herd and pen sizes. At present most of the recommended levels are based upon empirical wisdom but have, nevertheless, withstood the test of time. Others can be considered no more than educated guesses that have yet to be substantiated by experiment.

The minimum rate of ventilation can be set according to one of several criteria, for example, air temperature or dust concentration. In each case an engineer needs to know the rate of production and the critical level of the pollutant before he can decide on the rate of ventilation needed to maintain the critical level. At present this approach can be used for the criteria of air temperature, relative humidity and the avoidance of condensation, and the concentration of carbon dioxide because only for these pollutants are the rates of production accurately known.

Ventilation for pigs and poultry

In the United Kingdom the regulation of air temperature is of prime importance for pigs and poultry where respiratory disease can, in many cases, be controlled by vaccination or eradication (Webster, 1982). For these species the rate of ventilation can be reduced to maintain a minimum temperature until the other criteria become limiting. This is illustrated in Figure 2 (from Wathes, Jones and Webster, 1983) which shows minimum ventilation rates for a 20,000 bird broiler house according to the empirical recommendation of Charles (1981) and the criteria of temperature (21°C), relative humidity (75%) and concentrations of carbon dioxide (CO_2) (0.3%) and ammonia (NH_3) (20 ppm). The rates of production of heat, moisture and gases are taken from the recent in-house measurements of Feddes, Leonard and McQuitty (1982). There is only a substantial difference between the minimum ventilation rates after 22 days of age: at 43 days the rates range from 8×10^3 m³/h (NH_3) to 26×10^3 m³/h (CO_2). Clearly the use of Charles' rate would mean that the CO_2 level exceeded 0.3% although the NH_3 concentration would be less than 20 ppm. The house temperature and relative humidity would be quite satisfactory. This example readily demonstrates the conundrum that faces all designers of ventilation systems who must decide which pollutant should be the first criterion for ventilation. For pigs and poultry, control of temperature probably has the greatest effect on economic performance and the ventilation system should be designed accordingly. In the absence of primary pathogens, these animals will not suffer from infectious respiratory disease although the degree of air pollution in pig and poultry buildings may be extremely high and cause considerable discomfort to both animals and stockmen. In these circumstances it is logical to consider means other than ventilation to improve air hygiene (e.g. filtration, electrostatic precipitation).

Ventilation for cattle, sheep and horses

The prime objective in ventilating cattle and sheep sheds and horse stables is the provision of "fresh" air rather than control of temperature (Wathes, Jones and Webster, 1983). Unfortunately, TLV's for airborne pollutants have not yet been defined for these classes of farm animals. Indeed, the scale which measures the degree of irritation or harm to the animal may not have a sharp cut-off but rather increases smoothly in severity. This implies that no level will be intrinsically safe and that the lowest concentration is the best. The minimum rate of ventilation for ruminants and horses must always be specified with the airspace per animal. Furthermore, when levels of dust and microbial aerosols are used as criteria for ventilation then their routes of clearance by other means must be taken into account, i.e. physical decay in the form of sedimentation and impaction on surfaces and, for microorganisms, death on aerosolisation. Clearance rates per hour (which would be equivalent to air changes per hour [ach] in the case where ventilation was the sole pathway of clearance) range from 1-10 h⁻¹ (particles with aerodynamic diameters of 0.1 – 10 μm) for the former to up to 1000 h⁻¹ for the latter. Figure 3, from Wathes, Jones and Webster (1983), demonstrates the relative importance of the different clearance routes. In this hypothetical example, each calf releases viable microorganisms at a rate equivalent to 10^6 h⁻¹. When the cubic capacity is 6 m³ per calf and the rate of clearance by all routes excluding ventilation, q_e = 10 h⁻¹, then the air change rate has a large effect on the concentration of viable microbes.

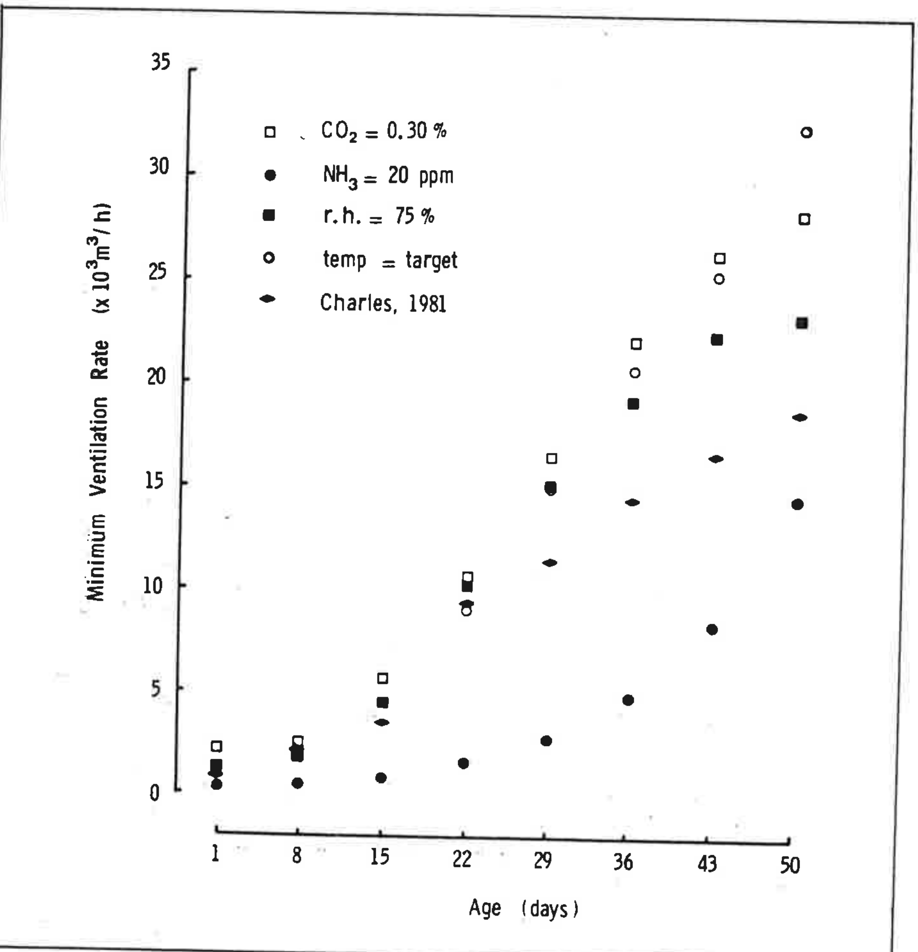

Fig 3 *Model relationship between ventilation rate, stocking density and concentration of airborne microbes. q_e = rate of clearance by all routes excluding ventilation. Published by kind permission of the Editor, The Veterinary Record.*

However, if q_e = 100 h^{-1}, then the impact of ventilation is much reduced. Moreover, doubling the cubic capacity obviously halves the concentration and, at 6 air changes per hour (ach), is equivalent to raising the ventilation rate to 30 ach at the higher stocking density. This suggests that manipulation of the building's climate to hasten microbial death rates or the installation of air filters may, in some circumstances, improve the air hygiene of animal houses as much as ventilation. In the particular case of calf houses, where the interaction between relative humidity and insulation must also be considered (see Wathes, Jones & Webster, 1983; Webster, 1984) then a minimum ventilation rate of 8 ach at a cubic capacity of at least 6 m³ per calf provides a sound foundation for good air hygiene.

Basic rules

There are three simple rules which should be followed when housing stock (such as bought-in calves) which are likely to be carrying respiratory pathogens.

1. Ideally, the age range of the animals within a common airspace should be narrow, say one or two weeks at most.
2. Only animals of similar previous experience should be grouped together.
3. An all-in, all-out policy should be adopted with proper cleaning and disinfecting and as long a period of rest as possible between batches.

Taken together, these three restrictions usually impose an upper limit on the number of animals which share an airspace.

Distance between buildings not significant

It was stated earlier that the survival time of some airborne microorganisms may be many hours. In this case then the distance separating buildings on the same farm and farms themselves must also be considered. In this context the most important infectious diseases are those in which the infectious agent has:

(i) a high output;
(ii) a low dispersion;
(iii) good survival when airborne; and
(iv) large numbers of susceptible animals are exposed for many hours (Gloster, 1983).

Good examples of diseases which meet these conditions are Foot-and-Mouth disease and Newcastle disease and models which forecast their long-range spread have been developed (Gloster et al, 1981). Using similar meteorological methods, Smith (1983) concluded that there was little scope for preventing the airborne transmission of disease by the physical separation of buildings on an individual farm. He also showed that at a distance of 10 km down-wind from a source of infection (of FMD or ND) then herds of cattle or flocks of poultry of the modal UK size were highly likely to contract the disease. The present size structure of UK farms, therefore, ensures that airborne transmission of highly infectious diseases is a realistic, ever-present threat.

Conclusions

The current threshold limiting values for noxious gases and inert dust which could be used in the design and operation of livestock buildings, are based on studies of humans rather than farm animals. No such values exist for airborne non-pathogenic bacteria, fungi and other microorganisms. An understanding of the mechanisms by which air pollutants may harm an animal's health is a fundamental prerequisite in building design. The rules of air hygiene, which are based on common-sense, empirical wisdom and fundamental science, can together help the designer of successful animal houses.

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