Special feature

Farm Animal Housing

Ventilation, air hygiene and animal health

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Veterinary Record (1983) **113**, 554-559

IT is a fundamental article of the veterinary surgeon's creed that adequate ventilation is essential to ensure good health and high productivity in housed livestock. However, when faced by the question 'What is adequate ventilation?', the clinician or consultant on farm building design may be hard pressed to provide a satisfactory answer because the criteria are complex, often conflicting and, in many cases, simply not known. Despite this shortcoming, both the original and recently revised British welfare codes for livestock include such terms as effective and sufficient when specifying ventilation requirements.

Ventilation of animal houses, whether mechanical or natural, serves to remove from the environment certain products of the animals' existence such as heat, moisture, carbon dioxide, dust, noxious gases and microbes, and to replace them with a supply of fresh air. Moreover, this fresh air must be distributed in a manner appropriate to the location of the stock and the design of the building.

Decisions as to the adequacy of ventilation for a particular livestock system can be obtained from simple records of performance and health in different circumstances. This empirical approach has proved successful, particularly in the poultry industry (Charles and others 1981) but it is, of course, open to the objection that it is only appropriate to the system of husbandry under study; extrapolation to other systems could be dangerous. The more fundamental approach is to measure rates of production and clearance of, eg, heat, moisture, dust, and to compare equilibrium concentrations of these things with acceptable standards. The major criticism of this approach is that, in many cases, there are no reliable standards for acceptability. Even for an intensively and scientifically managed animal like the pig it is only possible to define ventilation adequately in terms of temperature, carbon dioxide, humidity and the occurrence of condensation (Bruce 1981). Threshold limit values for such things as dust, total airborne bacteria or specific respiratory pathogens are quite unknown.

Criteria for ventilation

The objectives of a ventilation system are to provide an aerial environment in which (i) the animals' health can be maintained and their productivity sustained; (ii) the stockman can accomplish his tasks in comfort and without risk to his health; and (iii) the building and its equipment are protected from corrosion or physical damage. The criteria against which a ventilation system can be evaluated include: the control of air temperature and air speed at animal height, the control of relative humidity and the prevention of condensation, and the maintenance of tolerable concentrations of gases, dust and airborne microorganisms.

In general, although there may be incompatibilities between the rates needed to satisfy two or more criteria, the minimum (and maximum) rate of ventilation will be set according to the first limiting factor for animal performance.

Thermal environment

Designers of animal houses have undoubtedly given most attention to the control of the thermal environment. In the case of pigs and poultry this makes good sense, since, in the United Kingdom at least, outdoor temperatures are usually too low to ensure optimal conversion of feed into animal produce for these species. Fig 1 shows the approximate extent of the range of thermal neutrality (or the range of air temperatures within which optimal productivity is possible) for a variety of farmed species. Ruminants and horses have a much wider thermoneutral range than pigs or poultry so that, for them, control of the thermal environment is less likely to be the first limiting factor on production. This point is discussed in more detail elsewhere (Webster 1981a).

In the absence of any other criterion, the values shown in Fig 1 can therefore be used as a basis for estimating a rate of ventilation for maintaining a desired building temperature in any external climate. The rate will depend on the stocking density, level of insulation of the building and feeding regime.

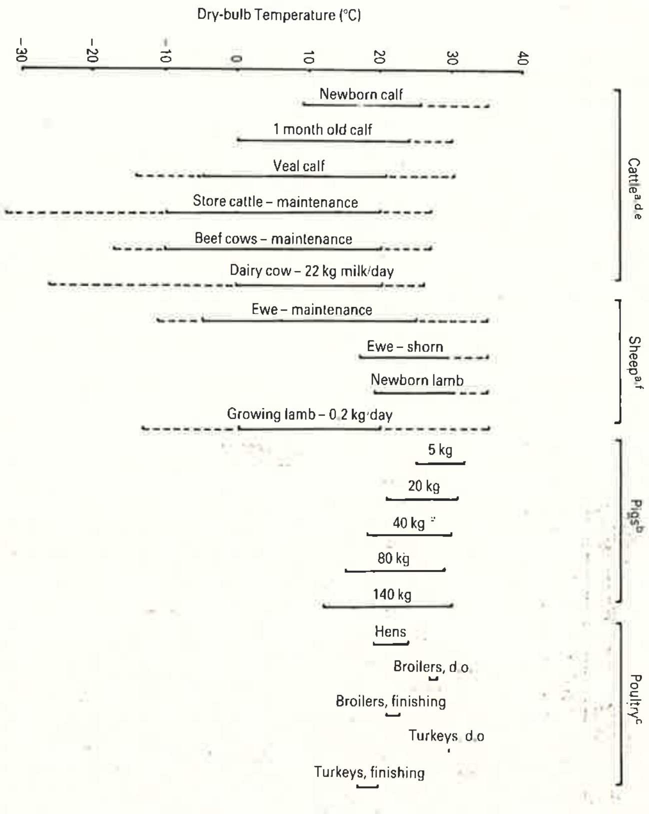

FIG 1: Recommended air temperatures within livestock buildings based on measured values of the upper and lower critical temperature and on production trials. Solid lines indicate ideal temperatures Dotted lines show the range over which an acclimatised animal can adapt. Sources: a – Webster 1981a, air speed = 0·2 m/s; b – Bruce 1981, solid concrete floor, group size = 10, feeding level 2 × maintenance, dry conditions; c – Charles 1981; d – Mitchell 1976; e – Webster 1974; f – Alexander 1974

The maximum ventilation rate is usually chosen to limit the temperature difference to 2° or 3°C above ambient. This figure is arbitrary and in some cases excessive (Owen 1982a).

A draught has been defined as an ill wind in the wrong place. A more precise definition might be an air speed faster than 0·3 m/s which leads to enhanced heat losses and chilling in cold weather. Draughts can be prevented by the correct design of air inlets, for example, positioning inlets well above animal height (Carpenter 1981, Randall 1981).

Moisture

A traditional criterion for the determination of a minimum ventilation rate is the moisture content of the house air. There are several reasons for this policy. First, saturated atmospheres lead to condensation on internal surfaces. However, provided the relative humidity (rh) is kept below about 75 per cent, this problem can be avoided if the structure is well insulated (Wathes 1981). In practice, only pig and poultry buildings are insulated, although this state arises more from their high temperature requirements than any consideration of condensation. Second, very high or low humidities (greater than 90 per cent or less than 30 per cent rh) are said to be detrimental to animal health (Sainsbury and Sainsbury 1979), although whether this is due to an enhanced challenge from infectious agents (because survival time is prolonged, see below) and, or, a reduced resistance of the animal host is not yet known (Webster 1981b). What is clear is that the effects of relative humidity on an animal's thermoregulatory capability are small in all but the most humid and hot climates (say greater than 80 per cent rh and greater than 30°C dry bulb).

Control of relative humidity is expensive. There are few experiments describing animal health and performance at different humidities and they are somewhat contradictory (Roy and others 1971, Jericho and Langford 1978, Kelly and others 1982). In consequence, recommendations for relative humidity in animal houses are vague, in the range 30 to 90 per cent, and the exact value has not been considered critical (Sainsbury and Sainsbury 1979).

Gases

The most common gases found in animal houses are ammonia, hydrogen sulphide, carbon dioxide, and methane. Nordstrom and McQuitty (1976) identified two main problems resulting from (a) acute exposure to lethal concentrations of manure gases liberated during emptying of slurry from stores beneath slatted floors; and (b) chronic exposure to lower concentrations throughout an animal's life. While occupational health standards for humans have been established and are 25, 10 and 5000 ppm for ammonia, hydrogen sulphide and carbon dioxide respectively (American Conference of Government Industrial Hygienists 1972), similar limits are not generally available for farm animals. These threshold limiting values suppose a repeated eight hour daily exposure, five days a week: housed animals must endure their atmospheres continuously and, in addition, may face several potentially harmful gases simultaneously.

Among the manure gases, hydrogen sulphide and ammonia are the principal offenders in cases of livestock poisoning. Hydrogen sulphide is an irritant at sublethal concentrations, causing inflammation of exposed surface tissues. In pigs, sudden exposure to a concentration of 400 ppm is lethal and the toxicity is related more to the gas concentration than the length of exposure (O'Donoghue 1961). Acute poisoning in cows and pigs, sometimes leading to death, is usually associated with agitation of aged liquid manure (Nordstrom and McQuitty 1976, Feilden 1982).

Like hydrogen sulphide, ammonia is an irritant which, in man, is detectable at 5 to 50 ppm and irritates mucous surfaces after an hour's exposure to 100 to 500 ppm (Nordstrom and McQuitty 1976). In hens at 100 ppm keratoconjunctivitis develops after six weeks' exposure and egg production is depressed, probably due to a reduction in appetite (Charles and Payne 1966). At 50 ppm the rate of infection by air borne Newcastle disease virus was double that of the control birds, which was possibly attributable to damage to the mucous lining of the respiratory tract (Anderson and others 1964).

In pigs, some authors report a depressant effect of high concentrations of ammonia (100 to 150 ppm) (Stombaugh and others 1969) while Curtis and others (1974), and Doig and Willoughby (1971) found no such effect, except when 50 ppm of ammonia was combined with high concentrations of dust (300 mg/m^3 Curtis and others 1974). Nevertheless, these last two reports suggested that even minor structural damage to the epithelium of the upper respiratory tract may lead to severe functional impairment and thus increased incidence and severity of lung diseases.

Methane and carbon dioxide are classified as simple asphyxiants and must be present in considerable amounts before they cause a noticeable effect. It is most unlikely that carbon dioxide or methane would become primary limiting factors on production or health in conventional animal houses.

Nevertheless, carbon dioxide is the only gas for which the rates of production are known accurately for all farmed species, and, as such, it can be used as a useful marker for determining the adequacy of ventilation with some precision. Control of concentrations of other gases must be determined empirically using the 'safe' limits of 5, 20, 300 and 3000 ppm for hydrogen sulphide, ammonia, methane and carbon dioxide respectively (Bruce 1981). The recommended levels of Stenning (1982) (8, 70, 1000, 50000 ppm) are probably too high and should be ignored. Bruce's levels are, of necessity, arbitrary and will change as more knowledge becomes available on, for example, the interaction between high concentrations of irritant gases and susceptibility to respiratory disease.

Aerosols – dust

Airborne dust in animal houses arises from three main sources, the animals themselves, in the form of skin squames; bedding or litter; and feed. Under most conditions very little dust is introduced into the building by the ventilation system.

Exposure to dust has been associated with pneumoconioses, allergies and toxic effects (Honey and McQuitty 1976). For example, dusty atmospheres in stables have been implicated in the aetiology of 'broken wind' in horses, although the precise involvement of an allergenic response has yet to be decided (Cook and Rossdale 1963, Cook 1976, McPherson and others 1979). Similarly the role of dust as a disease vector in poultry has been proposed by Carlson and Whenham (1968) for coli-septicemia and by Jurajda and Klimes (1970) for Marek's disease.

The evidence that chronic exposure to dust increases susceptibility to respiratory infections is conflicting and, in the case of carbon dust, refers to changes in ciliary function, clearance of bacteria by alveolar macrophages and bactericidal properties of the lung (Casarett 1960, Wright 1966, Miller and Zarkower 1974). Reviewing this subject, Holt and Keast (1977) concluded that dust may stimulate or depress the human immune system, this largely depending on dose and duration of exposure. This work has not yet been extended to farm animals though this is desirable if the argument over the

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hazards of dusty livestock buildings is to be resolved.

Studies of airborne dust can be, and indeed often are, bedevilled by the many descriptions of particle size and shape (Morrow 1974). The fate of an inhaled dust particle and the subsequent hazard to the animal depends on the site of deposition, the retention time at this site and along the routes of elimination and the physical, chemical and biological properties of the particles. Studies on this topic are more advanced in man than farm animals (Lippman and others 1980, Davies 1982) and are, in the main, outwith the scope of this article. Briefly, particles of an aerodynamic diameter greater than 5 μm are deposited in the upper respiratory tract while those below this size penetrate as far as the bronchioles and alveoli.

For the housed farm animal, background dust concentrations are highest in pig buildings and lowest in cattle and sheep houses, but are nearly always below the threshold limiting value of 10 mg/m^3 for inert dust (Honey and McQuitty 1976, Cermak and Ross 1978). Levels of dust exhibit marked diurnal cycles and, in a stable at least, are highest during stall rebedding and feeding (Crichlow and others 1980). Other factors which influence dust levels include animal activity, temperature and relative humidity (Honey and McQuitty 1979).

In their 1976 review Honey and McQuitty concluded that while there was no apparent correlation between dust concentration and performance in healthy animals, dust may be of importance with respect to respiratory disease. It is disappointing that the link between dust and respiratory disease has not yet received a thorough investigation.

Aerosols – microbial

Microbial aerosols include bacteria, viruses and fungal spores. Much of the quantitative work on microbial air pollution has involved measurement of viable bacterial colony-forming particles on nutrient agar. Two things must be stated at the outset, first the majority of these BCFP are not, in themselves, pathogenic, and secondly that bacterial particles do not necessarily need to be viable to produce an immune response or otherwise embarrass the respiratory tract.

The origins of airborne microbes are similar to those of dust; ie, the animals themselves and the bedding. In man, both aerobic (Noble 1981) and anaerobic bacteria (Benediktsdóttir and Hambraeus 1982) reside on the skin in discrete microcolonies, each containing between 10^2 and 10^5 cells (Noble 1975), and are dispersed into the air on rafts of skin squames (Noble 1981). Only about 4 per cent of squames from healthy men carry viable bacteria (Noble and Davies 1965) but these are sufficient to contaminate the air of operating theatres and wards, for example with *Staphylococcus aureus* (Noble 1981). The median aerodynamic diameter of the rafts is about 14 μm with a considerable range in size of the individual particles (Noble 1975). Similar observations on this and other routes of dispersal have not yet been made in animal houses but the same mechanisms are likely to hold (Lacey and Gregory 1980).

Once airborne, the survival of microorganisms depends on temperature, humidity and, under natural conditions, non-ionising radiation (Strange and Cox 1976). These effects are complex and vary considerably between species of viruses or bacteria (Donaldson 1978). Typical values for the survival time of individual organisms may range from a few seconds to many hours (Donaldson and Ferris 1976, Müller and others 1981). For many of the claimed respiratory pathogenic bacteria, mean survival times in the air are of the order of a few seconds rather than minutes (Jericho and others 1977). The data on fungal spores are sparse but one can assume that they survive in air considerably longer than, for example, *Pasteurella* species. Mycoplasmas are sensitive to relative humidities between 40 and 70 per cent (Donaldson 1978). Some bacteria show narrow zones of instability (2 to 3 per cent) at mid-range humidities (Hyslop 1971) and rapid fluctuations of humidity may further reduce a microbe's viability (Hatch and Dimmick 1966). There is some evidence (Dimmick and others 1979) that bacteria can even replicate in the airborne state.

There have been many surveys of airborne bacteria in animal houses (Honey and McQuitty 1976, Curtis and Drummond 1982), which recorded mean concentrations of about 60 bacterial colony forming particles per litre. Levels of bacteria are influenced by the same husbandry factors which govern dust levels, such as agitation of bedding and feeding.

The question of whether high concentrations of non-pathogenic organisms are harmful to housed livestock has yet to be answered. In one well-conducted experiment, filtration of recirculated air within a calf unit both lowered the concentration of airborne bacteria and was associated with a reduced incidence and severity of clinical and subclinical respiratory disease (Pritchard and others 1981). However, until this hypothesis has been examined further and measurements made of the rates of production of bacteria from bedding and animals, then levels of airborne bacteria can only be tentatively used as a criterion for ventilation rates.

Strategies for ventilation

Minimum ventilation rates

To recapitulate; temperature, carbon dioxide, relative humidity and the risk of condensation can all be used as criteria on which to base minimum ventilation rates. This approach is particularly applicable to pig and poultry houses where temperature is of prime importance and respiratory disease can, in many cases, be controlled by vaccination or eradication (Webster 1983). For ruminants and horses it may be safely assumed that the prime objective is to provide fresh air, ie, acceptably low concentrations of airborne pollutants. Although there is not yet sufficient knowledge of airborne pollutants in animal houses, a strategy for ventilation can be outlined which takes them into account.

Current guidance on minimum ventilation rates for all classes of farm livestock is shown in Fig 2. The recommendations are for the most part based either on experimental

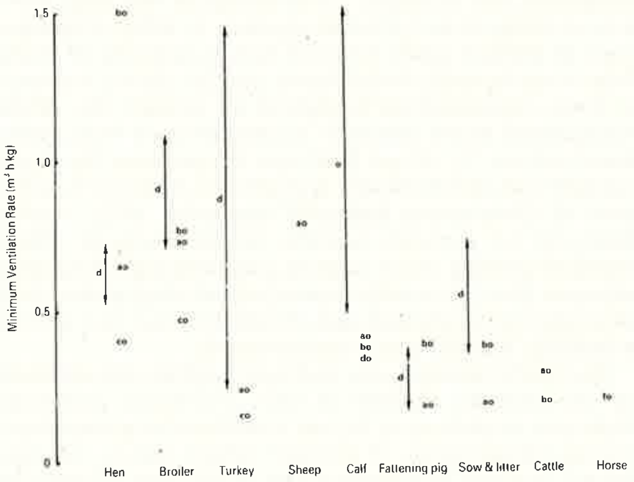

FIG 2: Recommended minimum ventilation rates for livestock buildings. Sources: a – Randall 1977; b – Sainsbury and Sainsbury 1979; c – Charles 1981; d – Ministry of Agriculture, Fisheries and Food 1981; e – Mitchell 1976; f – Sainsbury 1981

observations of animal performance (Charles 1981) or on clinical impressions of what constitutes adequate ventilation (Sainsbury and Sainsbury 1979). The rates shown for pigs and poultry are rightly concerned with control of temperature but those for ruminants and horses appear to have no fundamental basis. For any one class the range of recommended rates is wide.

The disadvantage of overventilating a pig or poultry house is obvious; it would get too cold. For ruminants and horses matters are less clear.

Air space allowance

There are very few recommendations for volume of air space per animal although it must be obvious that, other things being equal, the cleanliness of the air with regard to airborne wastes from an animal must be directly proportional to the volume of air into which those wastes are dispelled. Conversely, concentration of pollutants is directly proportional to stocking density. When ventilation rates are expressed as m^3 per hour per head, or per kg, or per kg $^{3/4}$ they become independent of stocking density. This is only a satisfactory description when ventilation is the sole or the dominant route for clearance of the pollutant. When other mechanisms of clearance, such as microbial death in situ, are important then stocking density and ventilation rate have to be considered separately and ventilation expressed as a clearance in air changes per hour (ac/h).

Clearance of airborne pollutants

The instantaneous concentration of any airborne pollutant is determined by its rates of emission (R, units per hour) and clearance (q, per hour). This is described by the following equation:

$$C(t) = C_0 e^{-qt} + \left(\frac{R}{qV} + \frac{q_v C_i}{q}\right)(1 - e^{-qt})$$

where C(t) is concentration of pollutant at time t (units/m^3), C_0 is concentration of pollutant at time 0 (units/m^3), q is rate of clearance by all routes including ventilation (q_v), sedimentation and, for live microbes, death after release into air (per hour), V is the volume of the building (m^3), and C_i is concentration of pollutant at air inlet (units/m^3).

In most buildings q exceeds 10 per hour and the exponential term becomes negligible after 15 minutes or so, leaving the familiar expression for the steady state concentration C of an airborne pollutant:

$$C = \frac{1}{q}\left(\frac{R}{V} + C_i q_v\right)$$

This expression is appropriate for gases, dust and microbial aerosols.

This equation appears complicated but there is no simpler way in which one may approach the truth of the matter, a fact recognised in *The Veterinary Record* by Martin in 1967. As an example of this expression consider the concentration of carbon dioxide in a broiler house of volume 1800 m^3 holding 12,000, 2 kg birds, each producing 4·6 litre/hour (Feddes and others 1982). The ambient concentration of carbon dioxide is 0·034 per cent. At a ventilation rate of 10 air changes per hours ($q = q_v$), the concentration within the building will be 0·34 per cent.

The advantages of expressing clearance rates in this manner (per hour) are, first, their values are independent of pollutant concentration, and, second, when several processes simultaneously remove pollutants from an air space, their combined effect is proportional to the sum of the individual rate constants (Bourdillon and others 1948). Clearance rates by sedimentation range from 0·1 to 10 per hour for 1 and 10 μm unit density particles respectively dispersed at 1 m height into air. In other words, small particles tend to remain in suspension for long periods. Clearance by ventilation is determined by overall ventilation rate (expressed as air changes per hour, and by the extent of mixing of air within the building. In practice, overall ventilation rates tend to range from 2 to 50 air changes per hour. Local rates of ventilation may vary two to three-fold from the overall mean (Lidwell 1960, Atomic Energy Research Establishment 1967, Sandberg 1981). Complete mixing is not always desirable. It is, for example, sensible to extract airborne pathogens from a building without complete mixing. It is also common practice to create cool spots in a pig house and so control dunging behaviour (Randall 1982).

As already indicated, death rates of airborne microbes are extremely variable. Typical values for individual organisms range from 0·1 to 1000 per hour (Müller and others 1981). When clearance by death in situ is, say 20 per hour and ventilation rate is 2 air changes per hour it follows that death in situ is ten times as important a mechanism of clearance as is ventilation. It has already been pointed out that microbial death rates are probably affected by, amongst others, humidity. If this is so, then the indirect effect of ventilation in controlling humidity may assume greater importance than its direct role of blowing microbes out of the building.

Other mechanisms which might also be used to remove airborne particles include filtration, ionisation and ultraviolet radiation. Practical devices employing the first two mechanisms rely on air recirculation and this limits their effective clearance rate to an equivalent of 20 or 30 air changes per hour. Owen (1982b, 1982c) discusses the relative merits of machines for collecting dust from animal houses and recommends filtration using propellor fans and large area filters.

Ventilation in practice

Proven designs of ventilation systems, especially those powered mechanically, have been developed at the Scottish Farm Buildings Investigation Unit, Aberdeen, the National Institute of Agricultural Engineering, Silsoe, and, for poultry, Gleadthorpe Experimental Husbandry Farm, Nottingham. Details are available from ADAS advisers and their principal features are described by, amongst others, Carpenter (1981), Randall (1981) and Bruce (1978). Most of these systems use thermal criteria for calculating minimum ventilation rates and it would seem appropriate from the foregoing discussion to examine the consequences of employing other criteria, taking as examples broiler chickens in a controlled environment building and young calves loose-housed in a naturally ventilated straw yard.

Ventilation for broilers

In Britain, ADAS recommendations for minimum ventilation rates for broiler chickens are based on the experiments of D. R. Charles conducted at Gleadthorpe Experimental Husbandry Farm (Charles and others 1981, Charles 1981, Ministry of Agriculture, Fisheries and Food 1981). In their work large flocks of broilers were kept at different minimum ventilation rates and their growth measured. Their results suggested that the minimum rates they had previously recommended for laying hens were also correct for broilers, namely 2 m^3/s for each tonne of food eaten per day; these

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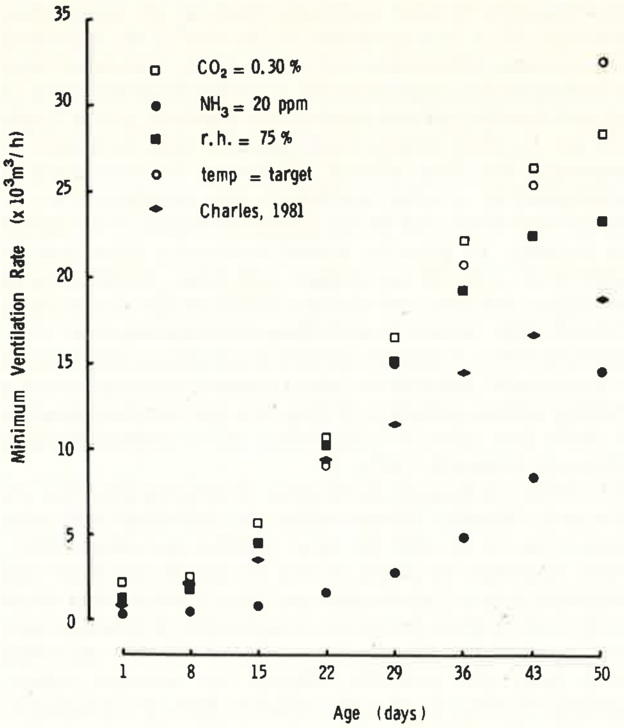

FIG 3: Minimum ventilation rates for broilers using four criteria. Building details: volume = 4000 m^3; floor area = 1440 m^2; ridge height = 6 m; eaves height = 2 m; overall U value = 0·5 W/m^2 °C; temperature = 31·5°C at 1 d reducing by 0·5 °C/day to 21°C at 22 days. Ambient conditions: CO_2 = 0·034 per cent; NH_3 = 0 ppm; moisture content = 4·85 g/m^3, 100 per cent rh at 0°C; temperature = 0°C. Rates for heat balance (temp = target) only shown after 22 days and are calculated without allowance for supplementary heating

have been widely adopted throughout the broiler industry.

Minimum ventilation rates for a flock of 20,000 broilers housed on litter at 20 birds/m^2 are shown in Fig 3 using the following four criteria as suggested earlier: carbon dioxide at 0·30 per cent; ammonia at 20ppm; relative humidity at 75 per cent; and air temperature at 21°C at 22 days. The rates of production of carbon dioxide, ammonia, moisture from both the birds and the litter, and heat were taken from recent measurements by Feddes and others (1982) in a commercial broiler house. For the first two weeks there is no difference between the rates using different criteria. However, once the birds are four weeks old there is a broad spread of rates which, at 43 days range from 8 × 10^3 m^3/h (ammonia at 20 ppm) to 26 × 10^3 m^3/h (carbon dioxide at 0·3 per cent). In practice, the adoption of a rate slower than the fastest minimum at any one age, would obviously mean that one or more criteria would be unsatisfied.

Ventilation for calves

It has been stated already that control of air temperature is of little importance for calves in terms of productivity in the healthy animal. In a house holding 25 calves (70 kg) at 6 m^3 per calf, carbon dioxide concentration could be kept below 0·3 per cent at 1·5 air changes per hour. However, Mitchell (1976) recommends, empirically, not less than six air changes per hour at a cubic capacity of 6 m^3 per calf to ensure good health, and reports from the USA indicate that lower ventilation rates and higher stocking densities are associated with very high (80 per cent) levels of clinical pneumonia (Bates and Anderson 1979, Weisbecker and others 1979).

Calf pneumonia describes a range of diseases which do not, in practice, appear to be attributable in a reproducible way to infection with specific causative organisms. For example, although Thomas and others (1982) recently identified five viruses, four species of mycoplasma and 19 species of bacteria in eight outbreaks of calf pneumonia, they were unable to ascribe the disease to either a combination of or any one particular microorganism in animals infected experimentally. Calf pneumonia has been called an environmental disease. Webster (1981a) argues that the primary effect of the environment is not to stress the animal in such a way as to reduce its resistance to infection, but to alter the magnitude and site of deposition of pathogens and other irritants to the respiratory tract so as to affect the incidence and severity of clinical disease. If this is so, then the prime objective of ventilation in a calf house is to clear the building of pollutants. In the case of live organisms this is achieved both by dilution and by influencing death rate in situ.

Fig 4 illustrates the effect of ventilation rate on relative humidity in an insulated and an uninsulated calf house, and shows that during mild, humid weather (ambient temperature 10°C, 90 per cent rh) the relative humidity in an uninsulated building never falls below 80 per cent while that in an insulated house reaches 75 per cent, at ventilation rates ranging from 5 to 15 airchanges per hour. At an ambient

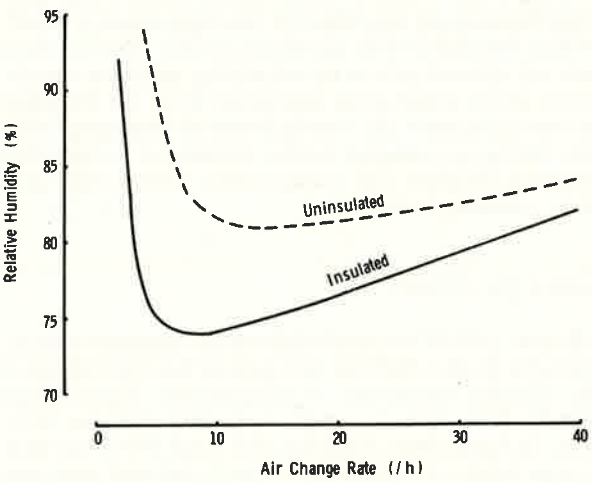

FIG 4: Relative humidity and ventilation rate in an uninsulated (– – –) and insulated (——) calf house. Building details: volume = 150 m^3; overall building heat loss = 0·3 and 0·6 kw/°C. Ambient conditions 10°C, 90 per cent rh

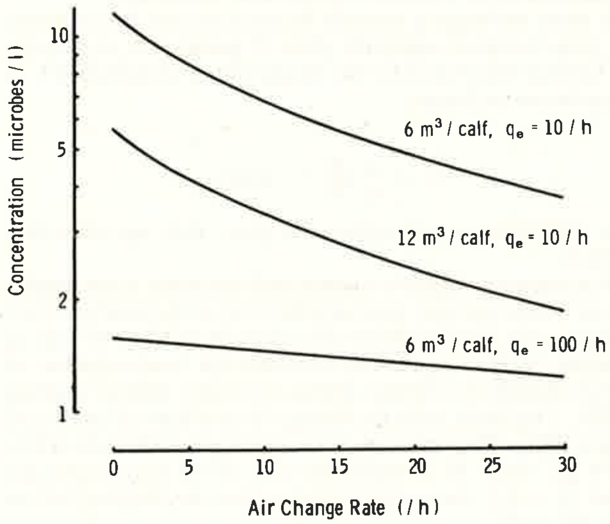

FIG 5: Model relationship between ventilation rate, stocking density and concentration of airborne microbes. q_e = rate of clearance by all routes excluding ventilation

humidity of 70 per cent rh the respective minima are 66 and 61 per cent. This small shift in relative humidity may cause a significant reduction in microbial survival time and therefore in the concentration of airborne bacteria if the implications of an earlier study are correct (Jones and Webster 1981).

A further illustration of the influence of ventilation on airborne microbes is shown in Fig 5 which assumes an hourly release rate from all sources equivalent to 10^6 microorganisms per hour per head. Doubling the air space allowance per calf from 6 to 12 m^3 obviously halves the concentration of organisms. To achieve (in this example) the same effect by ventilation it would be necessary to increase the rate from 6 to 30 air changes per hour. This illustrates a point of the greatest practical importance. For those pollutants such as bacteria for which death in situ is a major route of clearance, it is not possible to offset the effects of a two-fold increase in stocking density by a two-fold increase in ventilation rate; a ten-fold increase would be more realistic. Manipulation of the environment to reduce bacterial survival time or the installation of air filters may, in many circumstances, be more appropriate.

Wisdom of the ages

The Army Manual on Animal Management (War Office 1908) specified a minimum of 8 to 10 air changes per hour and an air space allowance of about 45 m^3 for stabled horses. Yet still today stables are built with ventilation systems quite incapable of supplying this quantity of fresh air. To many cost-conscious designers the Army Manual may seem impossibly generous. Designers of intensive houses for pigs and poultry have achieved large increases in productivity by increasing stocking density and decreasing ventilation rate on a scientific basis to meet the primary criterion of temperature control. In the absence of primary respiratory pathogens, they have usually got away with this in terms of animal health, although in many cases the level of pollution may be unacceptable in terms of animal welfare (Fig 3).

It would not, however, be a wise man who concluded that the incidence of respiratory disease in housed calves and horses was significantly better now than in 1908. The empirical standards of the Army Manual may not appear so extravagant when the scientific basis of space allowance and ventilation is calculated according to proper standards of air hygiene. It is sometimes more useful for science to explain the empirical wisdom of ages than to ignore it.

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