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Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses

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Abstract 1. A survey of the concentration and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin was undertaken in 4 examples each of typical UK broiler, cage and perchery houses over 24 h during winter and summer.

2. Overall the air quality within the poultry houses was unsatisfactory as judged by the dual criteria of farmer health and bird performance.

3. Mean concentrations of ammonia ranged from 12·3 to 24·2 ppm while concentrations of methane and nitrous oxide were close to ambient levels. Mass concentrations of aerial dust ranged from 2 to 10 mg/m^3 and 0·3 to 1·2 mg/m^3 for inspirable and respirable fractions respectively, while endotoxin concentration was typically about 0·1 $\mu g/m^3$ (inspirable fraction).

4. Emission rates of gaseous ammonia were rapid (9·2 g (NH_3)/h per 500 kg live body weight) and uniform across the three types of building, while emissions of methane and nitrous oxide were slow. Rates of dust emission ranged from 0·86 to 8·24 g/h per 500 kg live body weight in the inspirable size fraction.

INTRODUCTION

Interest in the quality of air in livestock buildings has grown substantially amongst agricultural engineers, environmental and animal scientists and veterinarians over the past decade. There are now numerous reviews of the subject (for example, Whyte, 1993; Wathes, 1994), that demonstrate the poor quality of air hygiene attributable to the heavy concentration of livestock in enclosed spaces. Equally important has been the recognition of a need to harmonise methodologies for sampling bioaerosols and gases to ensure comparability between studies in livestock buildings and other industrial workplaces (Wathes and Randall, 1989; Wathes, 1995).

The high concentrations of aerial pollutants in livestock buildings are of concern for two reasons. Firstly, there is some epidemiological evidence that farmers' health may be harmed by regular daily exposure to heavy burdens of aerial endotoxins, which arise from lipopolysaccharide membrane fragments of Gram-negative bacteria, non-specific nuisance dusts and irritant gases, particularly ammonia, at doses that approach and may exceed current long term occupational exposure limits (8 h time-weighted averages) (Donham, 1987; Whyte, 1993). Equally, animal health may be compromised by continuous exposure to these pollutants which potentiate infection and disease by opportunistic respiratory pathogens, for example, atrophic rhinitis in pigs (Hamilton *et al.*, 1993). Secondly, livestock buildings are a major anthropogenic source of atmospheric pollutants, such as ammonia, nitrous oxide, methane and carbon dioxide, which contribute to soil acidification and global warming (Jarvis and Pain, 1990; Asman, 1992; van Amstel, 1993; ECETOC, 1994; Williams, 1994). Recognition of this latter concern is comparatively recent and reflects the shortage of field data of emission rates to the atmosphere from this source.

This paper describes recent field measurements of the burdens and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK poultry houses from broilers kept on litter, and laying hens kept in battery cages and percheries. It is part of a wider survey of pollutant levels in typical livestock buildings in Northern Europe that uses common techniques to ensure comparability between data sets. The methodology of this study for sampling bioaerosols followed the relevant earlier recommendations of a European Workshop on aerosol sampling in animal houses (Wathes and Randall, 1989), while the methodology for sampling the gaseous pollutants is in accord with current best practice. The measurements were made in a number of poultry houses over 24-h periods during winter and summer and, in this sense, are restrictive, especially in broiler houses in which changes

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in litter composition over a crop's lifespan may alter the production of aerial pollutants, such as ammonia. Long term studies in a smaller number of livestock buildings are in progress to provide complementary data.

MATERIALS AND METHODS

Measurements of the concentration and emission rate of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin were made in 12 poultry houses, equally divided between broilers reared on deep litter and laying hens in battery cages and percheries. Data on nitrous oxide were collected only in the summer months because this additional measurement was included after the start of the main survey. Table 1 gives details of the poultry houses with representative plans shown in Figure 1. The buildings were chosen to be representative of their type as found in southern England. Percheries were included even though only about 4% of UK egg production is from colony-housing systems such as these, while the majority ($\approx$ 80%) of laying hens are kept in battery cages (Mercer, D.R., unpublished report to MAFF, 1993). Broiler chickens are nearly always reared on deep litter in a common type of building. Free range systems ($\approx$ 15% of laying hens) were not included because there is not the same concern for the bird's respiratory health, though measurements of emission rates of gaseous pollutants from hens at pasture would be useful.

Each house was monitored once over at least 24 h in winter and summer using the same methods. The division between winter and summer was by calendar month, though in practice the ambient weather was, on occasions, similar. Mechanical systems of ventilation were used in all buildings, in which the rate of ventilation was adjusted automatically to maintain a target air temperature. Therefore, building ventilation rates tended to be slower in winter than in summer because of colder ambient conditions. Strict hygiene precautions were taken to avoid disease transmission between the farms.

Details of the methods for measuring the burdens and emission of aerial pollutants and associated variables are given elsewhere (Phillips *et al.*, 1995) but are described here in brief (Table 2). All measurements were made at 7 locations within each house in a transverse cross-section close to the building's centre (Figure 2). Six of the sampling locations were either within the bird's or human's breathing zone respectively, that is, at heights above the floor of 0·5, 0·4, 1·2 m for locations 1, 3 and 5 and 1·5, 1·5 and 2·0 m for locations 2, 4 and 6 for broilers, perchery and cage houses respectively. The 7th location was placed $\approx$ 0·5 m from an opening identified as an outlet, either in the ridge or sidewall depending on the design of the ventilation system. Gas samples were collected hourly in sequence at each location and transported at 5 l/min via a Teflon pipe network to a central valve switching unit, from which a sub sample was obtained for gas analysis at a flow rate of 0·5 l/min. The section of pipe connecting the poultry house to the instrument trailer in which the various gas analysers were housed was insulated and heated to $\approx$ 30°C with electrical heating tape to avoid condensation. The concentrations of ammonia were measured by chemiluminescence after conversion to NO at 750°C (Thermo Electric Instrument Co., USA, model 42D). The concentrations of nitrous oxide, methane and carbon dioxide were measured directly with separate infra-red gas analysers (ADC Model 7000 series, UK). All analysers were calibrated for zero and span before and after each session. Samples of airborne dust in two size fractions, inspirable and respirable, were collected

Table 1. *Details of the poultry houses*

Building number	Number of birds S	Number of birds W	Mean bird weight (kg) S	Mean bird weight (kg) W	Age of birds S	Age of birds W	Floor area (m^2)	Building volume (m^3)	Ventilation systems[1] Type	Inlet	Outlet	Lighting regime (h)	Manure systems
Broilers					Days								
27/94	12720	14069	1·24	1·29	29	29	612	1866	N	R	E	24 h on	Litter
67/32	14095	13900	1·16	0·95	30	24	605	1496	N	R	E	"	"
69/33	13880	13900	1·50	0·97	35	25	605	1496	N/P	R[2]	E	"	"
70/34	14180	14050	1·61	1·00	34	25	605	1496	N/P	R	E	"	"
Caged hens					Weeks								
60/46	27178	27601	2·02	2·10	49	18	990	3119	N	R	D	14 h on	Deep pit
61/47	26334	26960	2·12	2·15	69	48	990	3119	N	R	D	"	"
63/48	27445	26747	1·99	2·18	29	66	990	3119	N	R	D	"	"
57/53	26499	26321	2·13	1.94	47	36	886	2481	P	R	D	"	"
Percheries													
64/50	5819	5975	1·98	2·15	69	50	299	868	N	R	D	14 h on	Slatted
65/51	6054	6155	1·92	2·12	49	54	299	866	N	R	D	"	floor and
66/49	6182	5260	1·86	2·18	29	68	613	1502	N	D	D	"	deep pit
58/54	15800	15918	2·30	1·82	43	34	886	2481	P	R	D	"	"

Key. S Summer, W Winter; N negative pressure, P positive pressure; R ridge, E sidewall, D deep pit wall.
[1] All ventilation systems had automatic control.
[2] Fans in this treatment were reversed in summer.

A

B

C

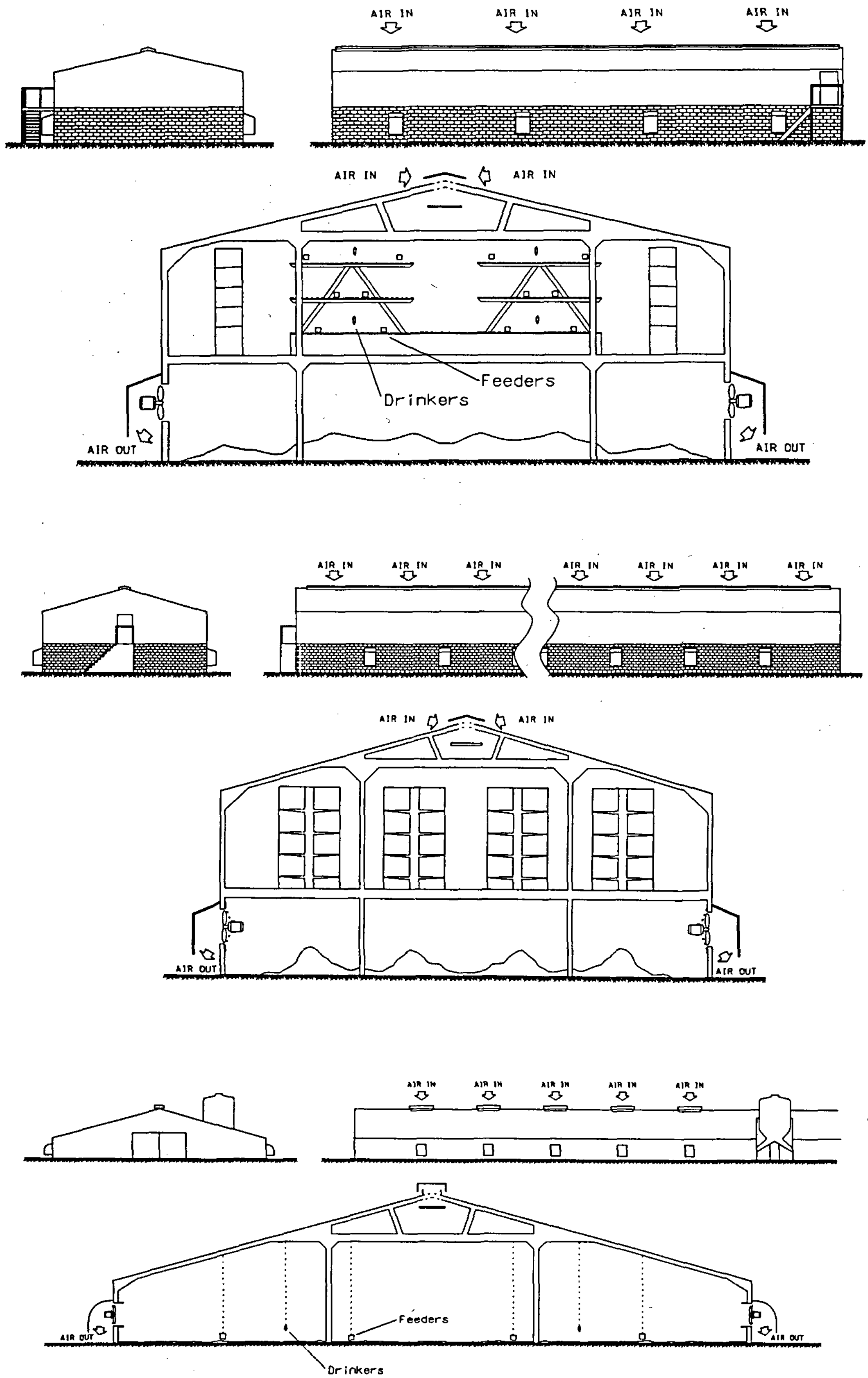


Figure 1. *External views and cross section of a representative (A) perchery (≈ 28·5 × 11 m), (B) cage house (≈ 90 × 11 m) and (C) broiler house (≈ 34 × 18 m) used in the study.*

gravimetrically on to glass fibre filters using IOM (Institute of Occupational Medicine) and cyclone samplers (SKC Ltd) respectively. Samples were collected over two 12 h sessions in each 24 h period from 06·00 to 18·00 and from 18·00 to 06·00 h. After exposure the filters were equilibrated overnight, at room temperature and humidity, weighed and the dust mass concentration calculated from the deposited mass and total volume of air sampled. The flow rate through the dust samplers was controlled at ≈ 2 l/min by a critical orifice. The concentration of endotoxin in the airborne dust was measured from a pooled sample of the 7 sampling locations for both inspirable and respirable size fractions using a LAL assay (Wiegand, 1994). Air temperature and humidity were measured every 6 min with a combined probe (Rotronic Model SA 200, Switzerland) and data transmitted to a data logger by radiotelemetry at a frequency of 458 MHz (Databus, UK). The gas analysers, the gas handling units, radiotelemetry signal receiver and data logger were housed in an instrument trailer sited close to the poultry house. At each site ambient dry bulb air temperature and air humidity at 2 m height, wind direction and speed at 10 m height were measured every 6 min at a remote site upwind of the poultry house.

The instantaneous emission rate of aerial pollutants leaving the poultry house is defined as the product of the instantaneous ventilation rate and concentration at the building exhaust, that is, measured at location 7 (Figure 2). The ventilation rate was calculated from a mass balance of carbon dioxide for the building that was based on estimates of CO_2 production by the poultry according to live body weight (van Ouwerkerk and Pedersen, 1994). The mean ventilation rate over 24 h was calculated from the hourly measurements of CO_2 and emission rates of ammonia, nitrous oxide, methane and dust were calculated from the 24 h mean concentrations at location 7.

The variation in the concentration of gaseous pollutants was examined by analysis of variance, assuming a completely randomised design after a

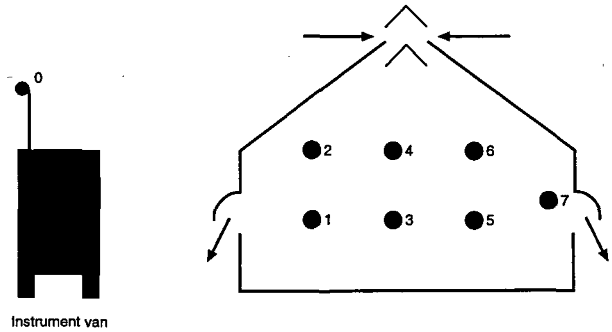


Figure 2. *Cross-section location of the sampling points.*

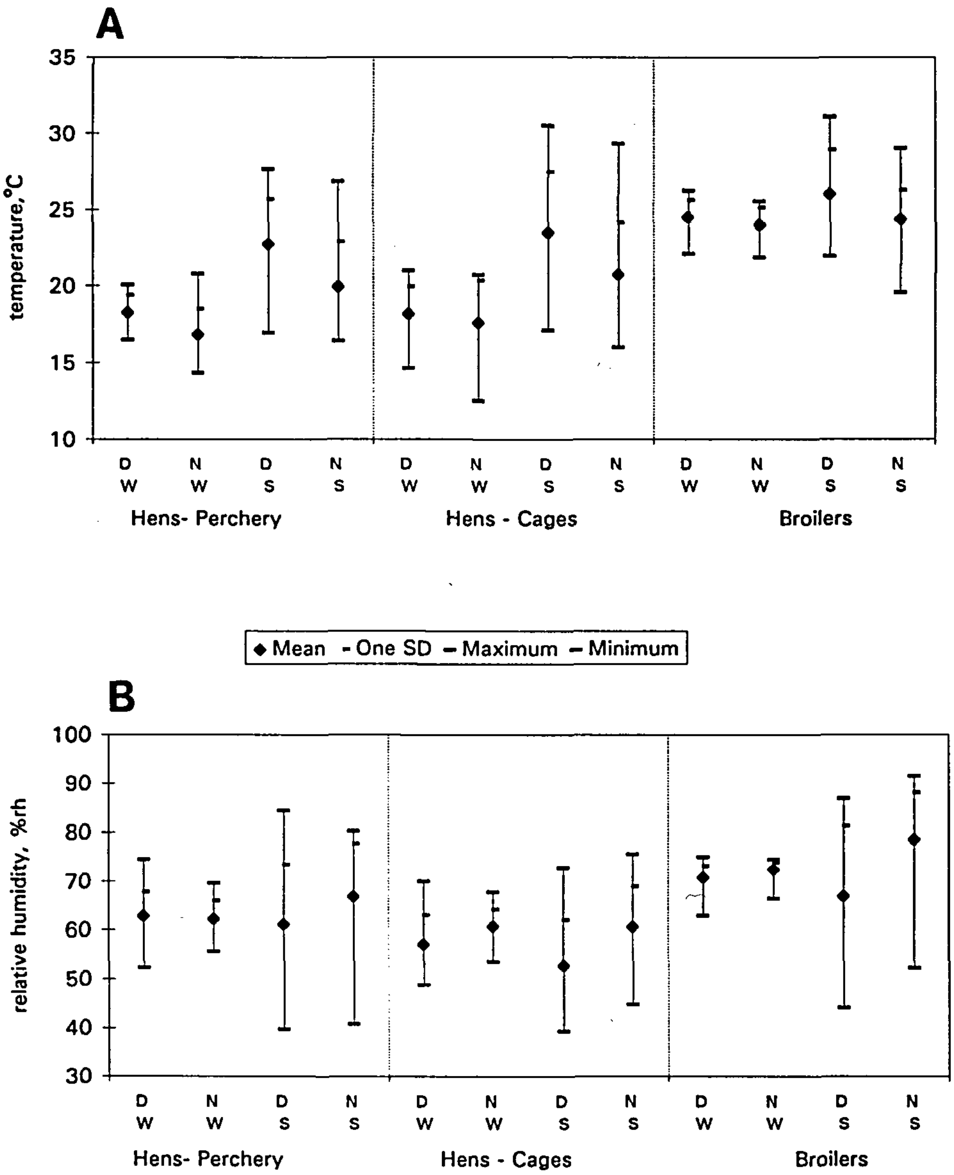
$\log_e$ transformation to stabilise the variance and to make the effects more additive. The main factors considered were the type of building, season and location (external, mean of locations 1 to 6 inclusive, and exhaust). Sampling height was also considered as a fourth factor but its effects were rarely significant and are not considered further. A $\log_e$ transformation was not necessary for the concentration of dust while the concentration of endotoxin required a square root transformation.

RESULTS

Figures 3A to 3F inclusive show the hourly mean, minimum, maximum and standard deviation for air temperature, relative humidity, and concentrations of carbon dioxide, ammonia, methane and nitrous oxide respectively. The data are based upon the average across the 6 locations (1 to 6, Figure 1) within the bird and human breathing zones and the derived statistics are calculated from 48 values (4 building replicates $\times$ 12 hourly values). As might be expected the mean temperatures (and relative humidity) within the broiler houses were warmer than the layer houses in both winter and summer. The mean concentration of carbon dioxide was consistently higher in all types of building in winter than summer with a correspondingly larger standard deviation and range. The overall mean concentration of ammonia was 12·3, 13·5 and 24·2 ppm at locations 1 to 6 inclusive in

Table 2. *Measurement techniques for emission of serial pollutants*

Variable	Technique	Location	Frequency
Ammonia	Chemiluminescence NO_x analyser	3 × animal height 3 × human height 1 × outlet 1 × ambient	Hourly
Nitrous oxide	Infra-red analyser	As above	Hourly
Methane	Infra-red analyser	As above	Hourly
Carbon dioxide	Infra-red analyser	As above	Hourly
Ventilation rate	Indirect mass balance of CO_2	As above	Hourly
Airborne dust	Gravimetric filtration	As above	12 h
Airborne endotoxin	Gravimetric filtration	As above but samples pooled	12 h
Air temperature	Thermistor	As above	6 min
Relative humidity	Capacitance sensor	As above	6 min
Wind speed	Cup anemometer	1 × ambient	6 min
Wind direction	Wind vane	1 × ambient	6 min

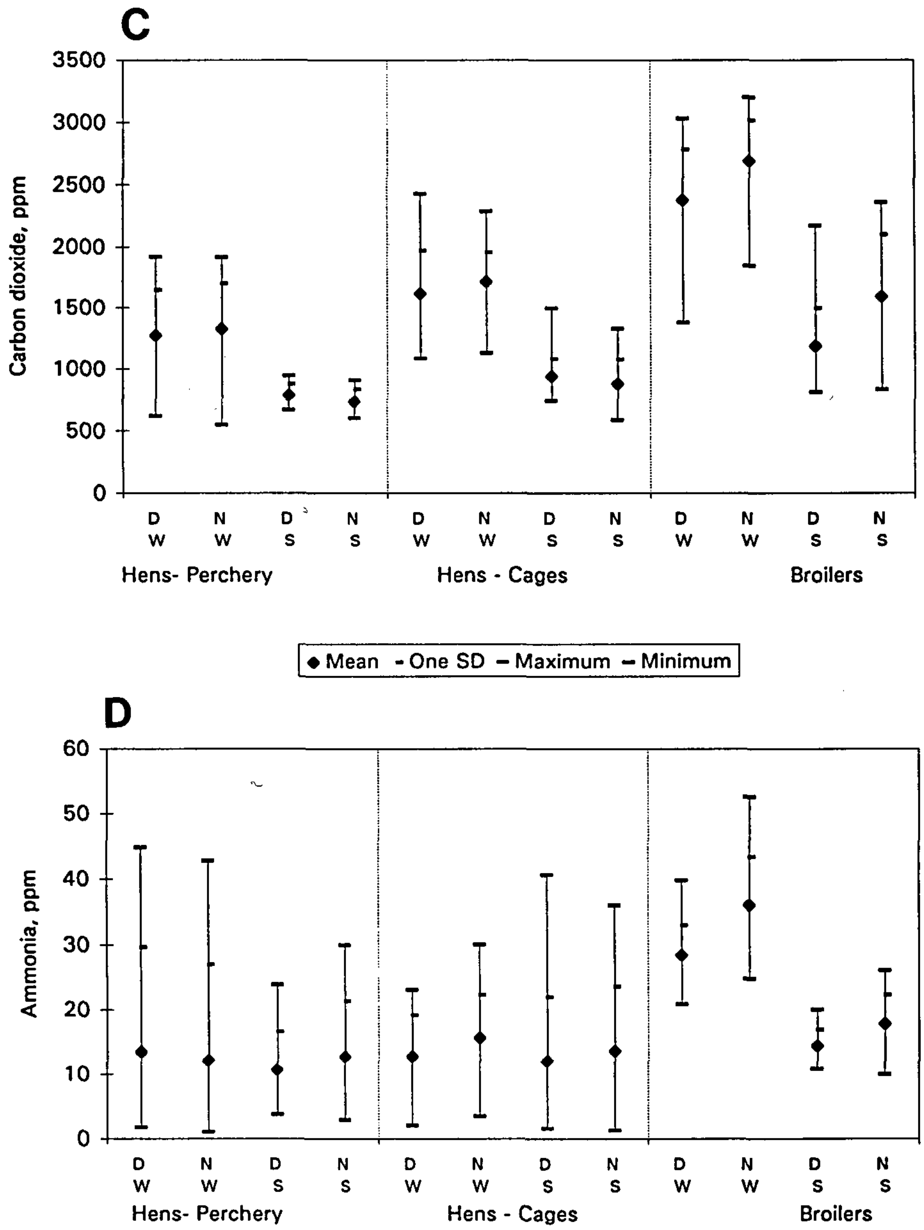


Figures 3A and B. *Mean (± SD, minimum and maximum, n = 48) hourly value of measurements for 12 h across locations 1 to 6 inclusive in 4 replicate buildings. A: air temperature; B: relative humidity. Key: D day, W winter, S summer, N night.*

the perchery, cage and broiler houses respectively, while the maximum hourly values of ammonia concentration exceeded 40 ppm. Minimum values of ammonia concentration were significantly higher in the broiler houses during winter but not summer ($P \leq 0{\cdot}001$) and were typically about 10 ppm in summer. Similarly, the overall mean concentration of nitrous oxide and methane was 0·2, 0·3 and 1·8 ppm and 4·2, 4·5 and 3·2 ppm in the percheries, cage and broiler house respectively. The differences in the concentration of methane between building types were significant ($P = 0{\cdot}03$), while for nitrous oxide the differences between types were affected by sampling location ($P = 0{\cdot}03$).

Mean hourly temperatures across locations 1 to 6 inclusive relative to external temperature for each building type are shown in Figures 4A to 4C respectively. Overall, these figures show the ability of each building type to control air temperature when external temperature varies. The external temperature above which control failed was about 12·5°C, 12·5°C and 17·5°C for percheries, cages and broiler houses respectively.

Figures 5A to 5D inclusive show the mean and standard error over a 12 h period (the duration of air sampling) for the mass concentration of airborne inspirable and respirable dust and endotoxin. The data for dust concentration were derived as above while the endotoxin data are based upon an aggregate sample across sampling locations 1 to 7 inclusive. The mass concentration of inspirable dust was greatest in broiler houses ($P < 0{\cdot}001$; sed = 0·45) and was usually higher during winter than summer ($P = 0{\cdot}034$; sed = 0·59) and during the day than at night with overall mean concentrations of 2·8, 1·7 and 10·1 mg/m^3 for percheries, cages and broiler houses respectively. Similarly, the mass concentration of respirable dust



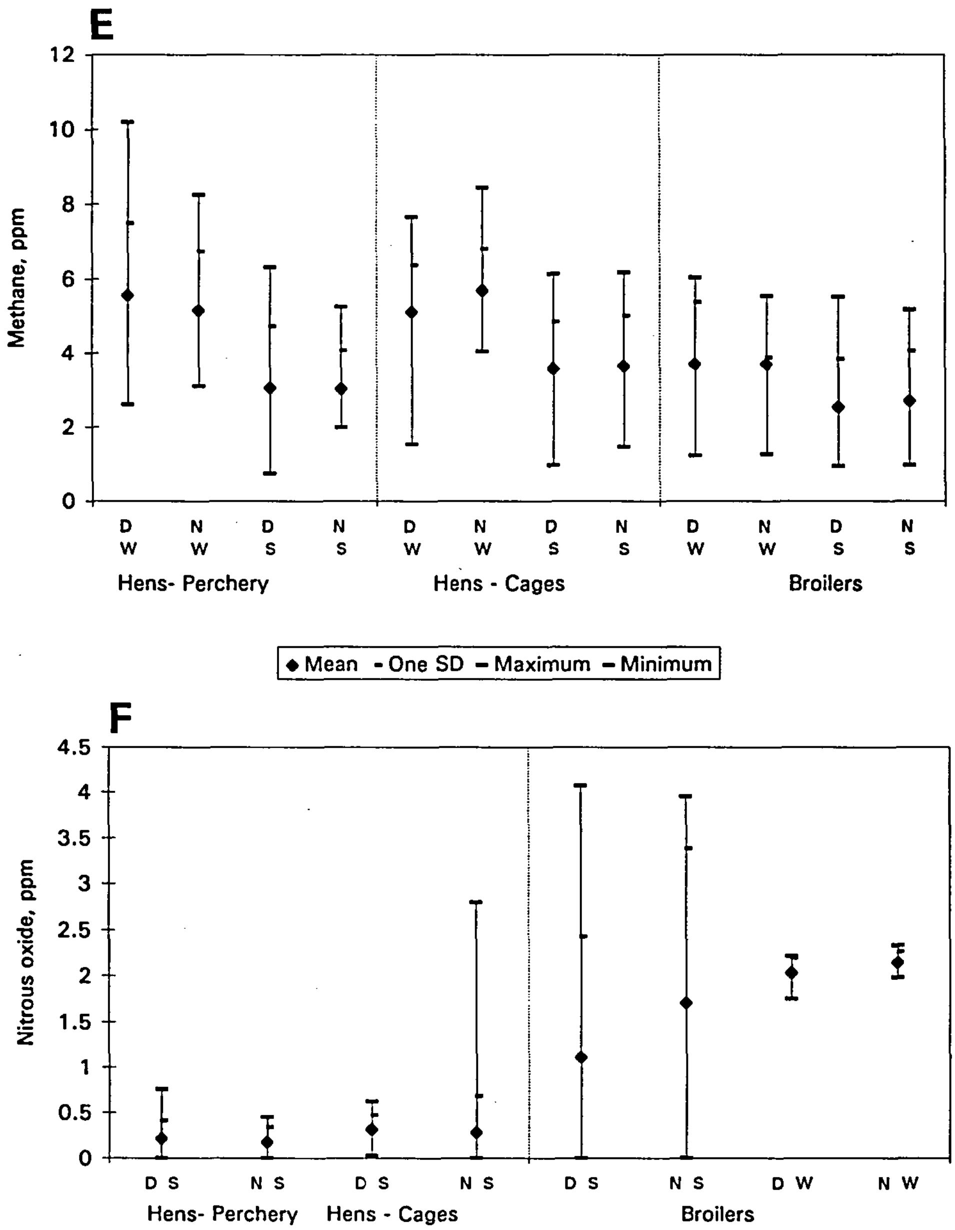
Figures 3C and D. *Mean (± SD, minimum and maximum, n = 48) hourly value of measurements for 12 h across locations 1 to 6 inclusive in 4 replicate buildings. C: CO_2 concentration; D: NH_3 concentration. Key: D day, W winter, S summer, N night.*

was heaviest in broiler houses ($P < 0.001$; sed = 0·064) and tended to be higher during winter than summer ($P = 0·063$) with overall mean concentrations of 0·40, 0·27 and 1·19 mg/m^3 respectively. The burdens of endotoxin were highest in the percheries ($P = 0·004$ and 0·07) with overall mean concentrations for percheries, cages and broiler houses of 0·17, 0·1 and 0·1 μg/m^3 and 16, 4 and 4 ng/m^3 for the inspirable and respirable fractions respectively.

Circadian patterns in the concentration of ammonia and methane at all locations are shown in Figures 6A to 6C inclusive for a typical perchery, cage and broiler house during winter. Close to the floor of the poultry house, there was little variation in ammonia concentration and the mean across locations 1 to 6 was close to the concentration at location 7, at the building's exhaust. A slight diurnal rhythm was evident for the layer houses but not all broiler houses. The circadian pattern of methane concentration followed closely the ambient concentration.

Table 3 presents the mean ventilation rate in the three types of poultry house as calculated over 24 h from the mass balance of carbon dioxide, expressed per unit of 500 kg live body weight or per kW of metabolic heat (sometimes termed a heat production unit). The ventilation rate was slower in winter than in summer. The large standard errors reflect the wide range in ventilation rate: for any one type of building in either season, the ratio of the maximum to the minimum ventilation rate varied between 1·2 and 5·4 and was typically about 2·0.

Mean emission rates over 24 h at location number 7 are shown in Figures 7A to 7F inclusive



Figures 3E and F. *Mean (± SD, minimum and maximum, n = 48) hourly value of measurements for 12 h across locations 1 to 6 inclusive in 4 replicate buildings. E: CH_4 concentration; F: N_2O concentration. Key: D day, W winter, S summer, N night.*

for inspirable and respirable dust, endotoxin, ammonia, nitrous oxide and methane respectively. Emission rates of dust of both size fractions were significantly higher in broiler houses compared to percheries and cage buildings and were little affected by season. The emission rates of endotoxin were highest from the percheries. For gaseous pollutants, emission rates of methane were lowest from broiler houses while emissions of ammonia and nitrous oxide were similar across all building types with an overall rate of 9·2 g NH_3/h per 500 kg and 0·59 g N_2O/h per 500 kg respectively.

DISCUSSION

Previous reports of air quality in poultry houses have usually concentrated on bioaerosols, particularly dust or ammonia, with few examples of a comprehensive study of the common gaseous and particulate pollutants. The mean concentration of ammonia in this study ranged from 12·3 ppm in the percheries to 24·2 ppm in the broiler houses with maximum concentrations over an hour above 40 ppm. It is likely that the ammonia concentration in broiler houses could be greater towards the end of the crop, especially if litter management was poor. These mean concentrations are close to or exceed the current exposure limits of 20 ppm for animal well being (CIGR, 1992) and are within the range reported in other studies (Whyte, 1993). The concentrations of carbon dioxide were within tolerable limits (CIGR, 1992). The measurements of the concentrations of methane and nitrous oxide appear to be novel. These gases were included in this survey to allow direct comparison with our measurements in pig and cattle buildings, which are in

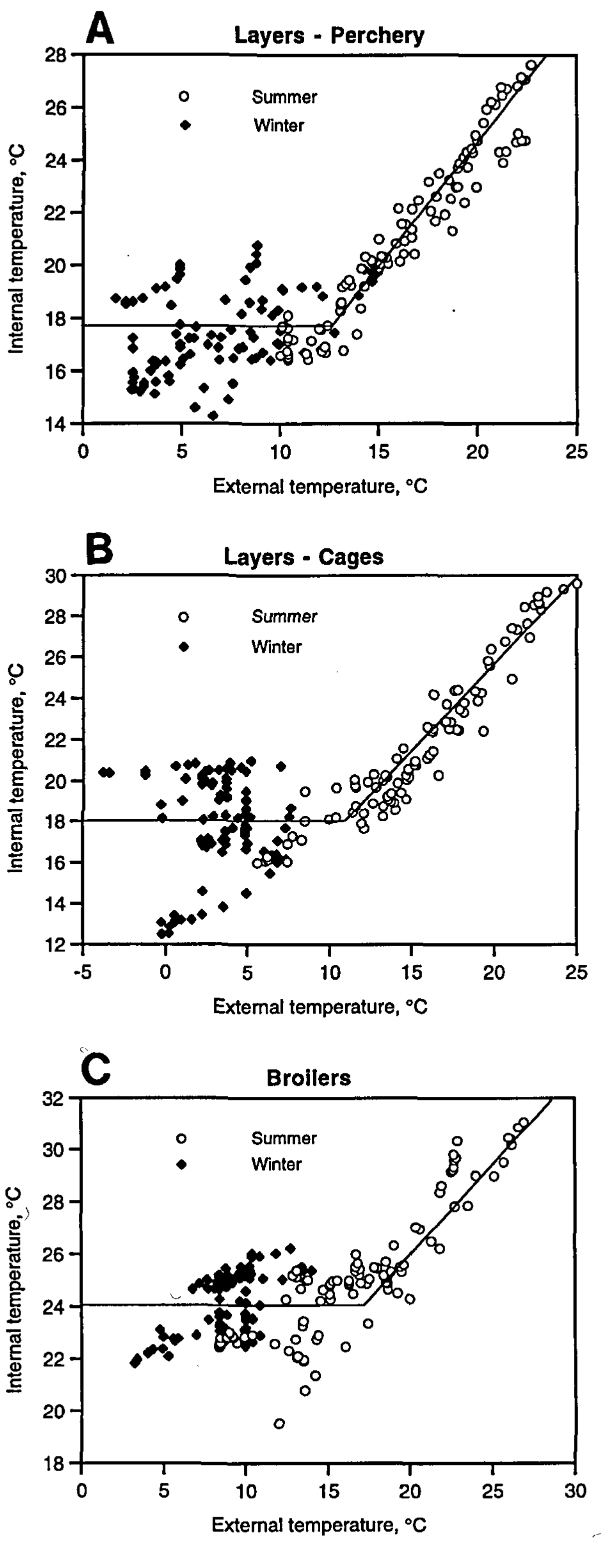


Figure 4. *Relationship between mean hourly internal temperature across locations 1 to 6 inclusive versus external temperature. A: percheries; B: cages, and C: broilers.*

progress. The concentrations of both methane and nitrous oxide were low and only slightly above ambient levels.

The mean mass concentrations of inspirable and respirable dust ranged from 2 to 10 mg/m^3 and 0·3 to 1·2 mg/m^3 respectively, and are also within the range of other studies (Whyte, 1993). The high concentrations of inspirable dust within broiler houses are close to the long term (8-h time-weighted average) exposure limit for nuisance dust of 10 mg/m^3 for humans (Health and Safety Executive, 1992) and greatly exceeded the suggested limit of 3·4 mg/m^3 for animals (CIGR, 1992). Similarly, the levels of aerial endotoxin in both size fractions in percheries are indicative of the large quantity of airborne spora, including cell fragments. Other studies have shown comparable levels (Whyte, 1993), which are likely to induce toxin fever in humans given prolonged occupational exposure.

Taken together, these measurements of the concentration of various aerial pollutants in poultry houses demonstrate a low standard of air quality by comparison with other livestock buildings or industrial environments. An important question is the likely effects that this poor air quality may have on either human or bird health and performance. The evidence for a serious or significant effect on occupational respiratory disease amongst a minority of poultry workers is growing. Poultry house dust has been implicated in the aetiology of chronic bronchitis, hypersensitivity pneumonitis and toxin fever (Whyte, 1993) and there are a number of studies reporting impairment of respiratory function in poultry workers (for example, Thelin *et al.*, 1984, Whyte *et al.*, 1993). Ammonia gas 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). However, as with many aerial pollutants in livestock houses, it is difficult to distinguish its separate effects on occupational respiratory diseases in poultry workers because of the lack of data on dose response relationships for single pollutants (Donham, 1987). In pig houses, Donham recommended a maximum endotoxin concentration of 80 ng/m^3, based upon a deterioration in pulmonary function. Pending other evidence and assuming a similar pathogenesis for endotoxin in poultry house air, then this guideline has clearly been breached in this study. While the health complaints of poultry workers are less frequent and less severe than those of pig workers (Donham, 1987), their overall performance is likely to be compromised by the poor air quality in poultry houses.

With regard to the effects on poultry, early work by Charles and Payne (1966) showed a depression in egg production and development of keratoconjunctivitis after 6 weeks exposure to ammonia at a concentration of 100 ppm. Both Anderson *et al.* (1964) and Oyetunde *et al.* (1978) have demonstrated that ammonia exposure increases susceptibility to respiratory infection in chickens, probably through damage to the mucous lining of the respiratory tract. The growth rate of broiler chickens is also affected adversely by atmospheric ammonia at ≥ 25 ppm during brooding (Reece *et*

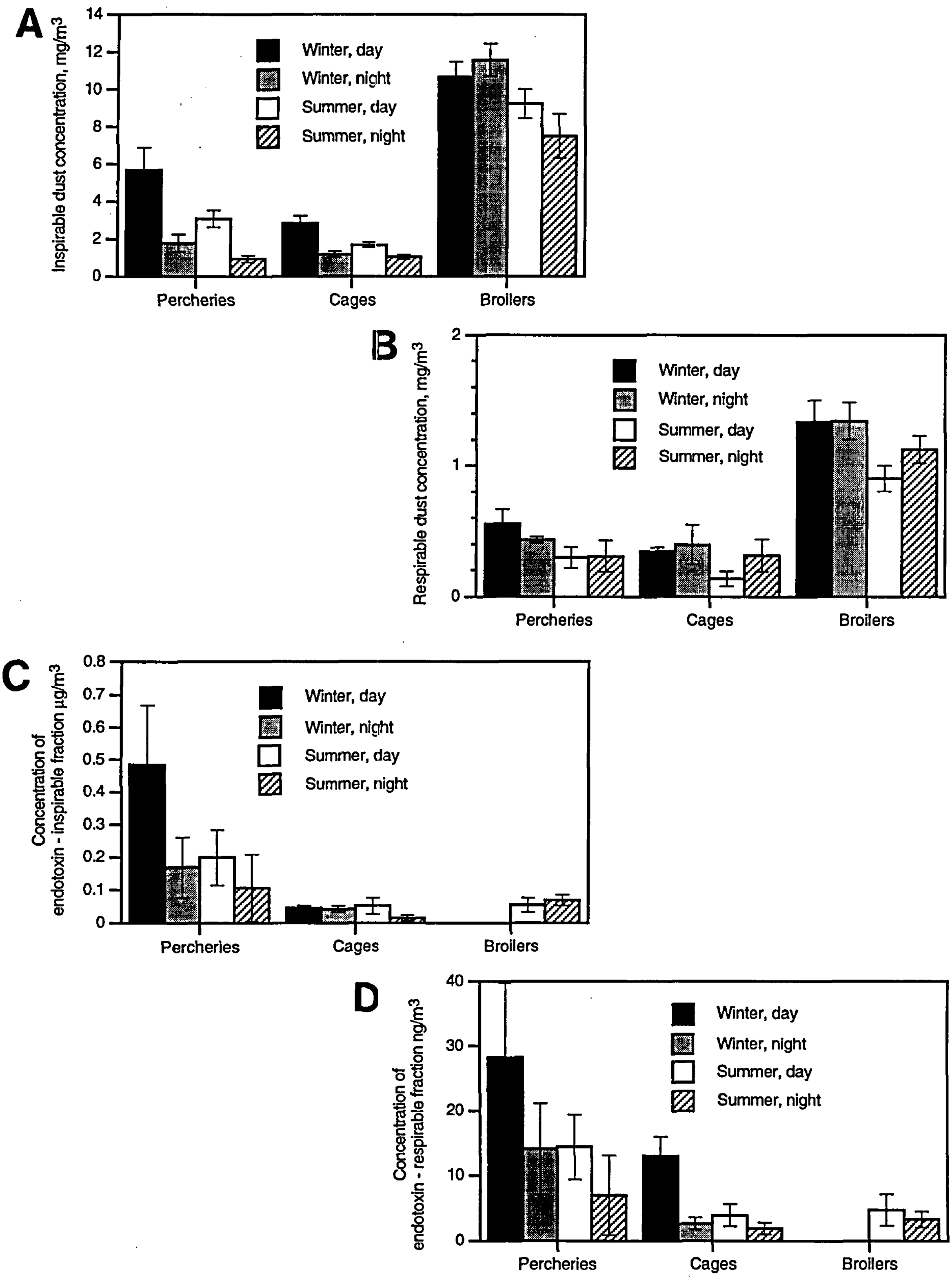


Figure 5. *Mean (± SE, n = 4) concentration of airborne dust over 12 h across locations 1 to 6 inclusive during winter and summer. A: inspirable dust; B: respirable dust; C: endotoxin inspirable fraction, and D: endotoxin respirable fraction.*

al., 1980; 1981) and at up to 50 ppm during growing (Quarles and Kling, 1974). While dust has been proposed as a disease vector in poultry, for example for Marek's disease (Jurajda and Klimes, 1970), there are few studies with poultry *per se*, though work with pigs has implicated dust in the aetiology of several respiratory diseases (Robertson *et al.*, 1990; Hamilton *et al.*, 1993). Overall, these studies suggest that the burdens of aerial pollutants recorded in poultry houses in this survey may be sufficient to compromise bird health and performance.

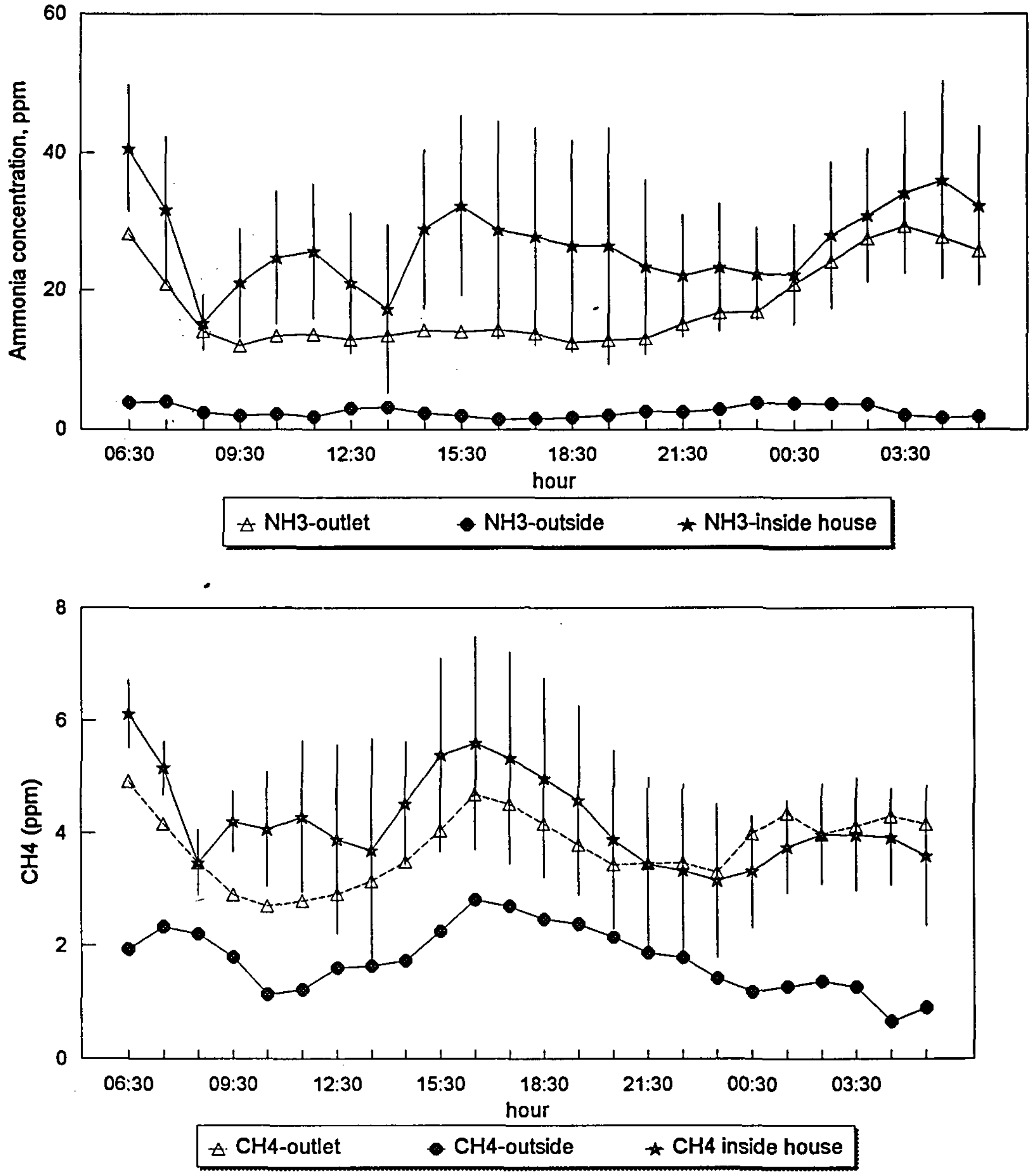


Figure 6A. *Circadian patterns and spatial variation in the mean* (± SD) *concentration of ammonia and methane: percheries.*

There are few comparisons of air quality in hen and broiler houses that have employed common techniques. It almost goes without saying that air quality is affected by many physical and biological factors: the animal species is the main common denominator in these studies. The age of the flock is especially important in measurements in broiler houses because litter composition can alter substantially over the crop's lifespan. The concentration of inspirable dust was higher in the day than the night in the hen, but not the broiler, houses. This was probably attributable to greater laying hen activity during the day and also the longer day length in the broiler houses, which would tend to eliminate circadian rhythms in feeding and other activities. The current trend towards the use of intermittent lighting programmes in broiler production would tend to lower the production of pollutants because of reduced activity of the birds. In our survey the concentrations of dust and ammonia were consistently higher in broiler houses than in percheries and cage houses. The higher levels of dust are to be expected because of the presence of litter and this confirms the findings of Whyte *et al.* (1993). Other colony housing systems that utilise litter may be expected to have higher dust levels than those reported here for percheries. Our findings indicate that there is little reason to prefer percheries to cages on the grounds of air quality; both have equally high concentrations of pollutants. Furthermore, there was no consistent difference between mean concentrations of ammonia during the day and night, which reflects the combined effects of changes in ventilation rate to control air temperature and generation rate. However, ammonia concentration was significantly higher in broiler houses in winter than summer: probably because the winter ventilation rate was half that in the summer, though the moisture content of the litter may also have played a part. The ventilation systems in all

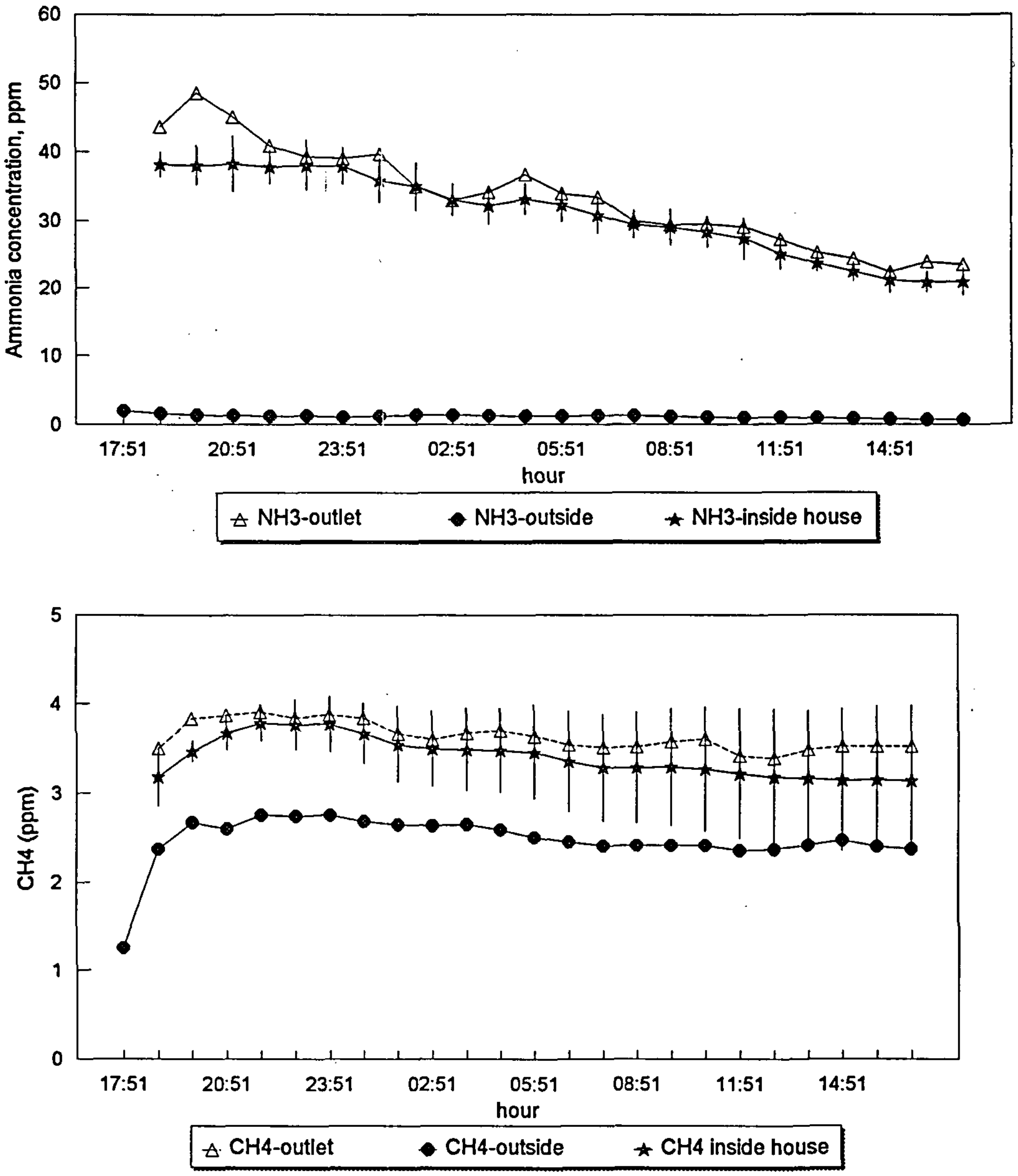


Figure 6B. *Circadian patterns and spatial variation in the mean (± SD) concentration of ammonia and methane: cages.*

buildings were controlled by thermostats according to house temperature, though stable building temperatures were only maintained in winter and the systems 'failed' at surprisingly cold temperatures. Generalisations about the notional effects of season upon ammonia concentration, or any other variate, are therefore limited because there are normally proper physical relationships to account for any apparent effects.

The second main aim of the survey was to quantify the emission rates of aerial pollutants from livestock buildings. The estimates given here were calculated from the product of the pollutant concentration at the exhaust and the time-averaged daily ventilation rate, after allowances for the ambient concentration of the pollutant. The sampling procedure at the exhaust was similar to that used elsewhere but it is obviously important to identify the exhaust location correctly. In mechanically-ventilated buildings, such as those in this survey, this is straightforward but identification is far more difficult in naturally ventilated buildings, such as those commonly used for cattle in the UK (Phillips *et al.*, 1995). Accurate measurements of ventilation rate can be made directly by deliberate release of gaseous tracers or anemometry in ventilation exhausts, but these techniques would not have been feasible in the survey, given the primary objective of classifying a large number of buildings of different types in a campaign of short-term measurements. Indirect estimation by means of a mass balance of carbon dioxide is the only feasible alternative and has been shown to be accurate to about 15% (Van Ouwerkerk and Pedersen, 1994). Overall the accuracy of the emission rates is estimated to be only ±20%.

The rates of emission of ammonia were approximately uniform across the three types of

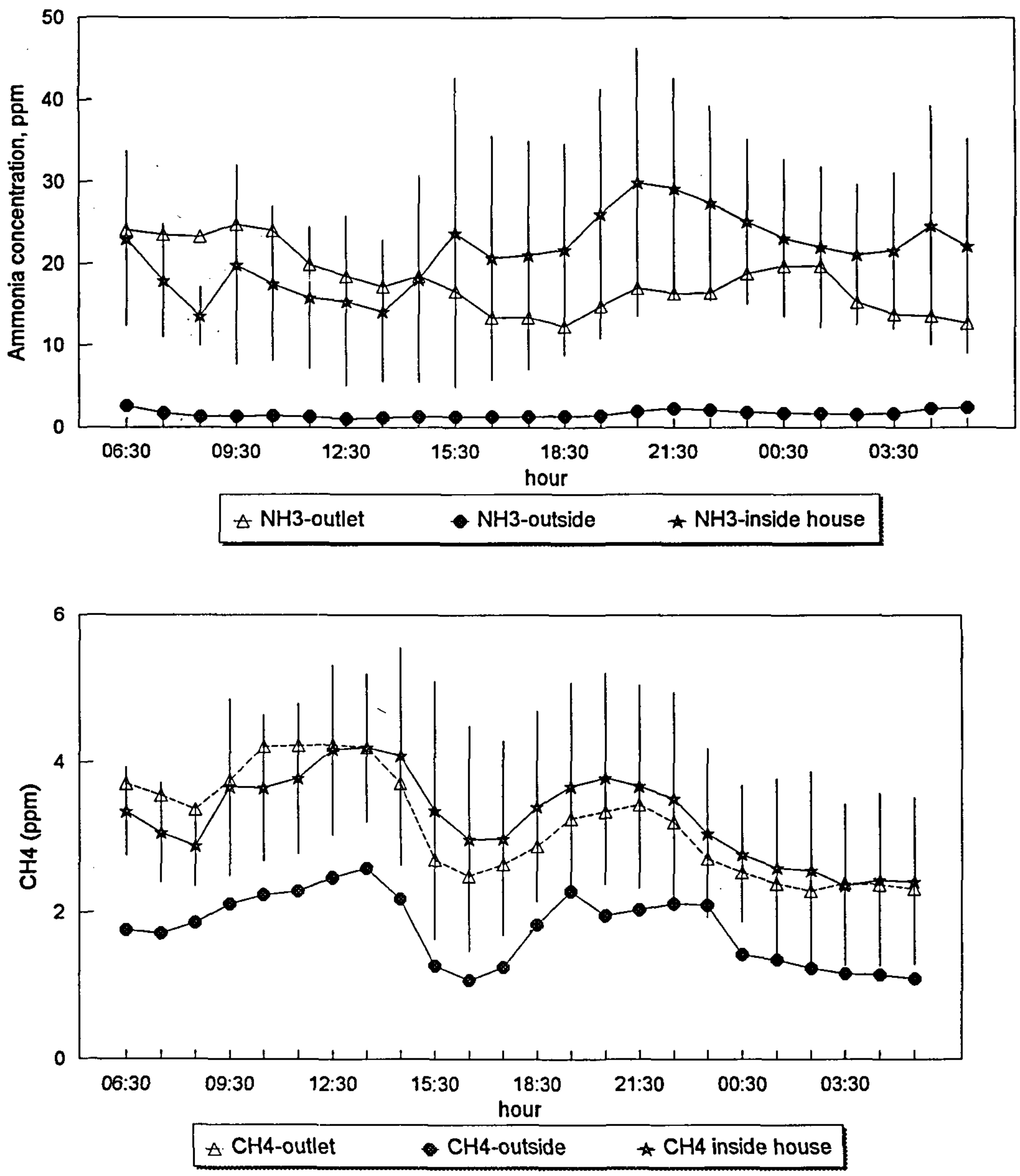


Figure 6C. *Circadian patterns and spatial variation in the mean (± SD) concentration of ammonia and methane: broiler houses.*

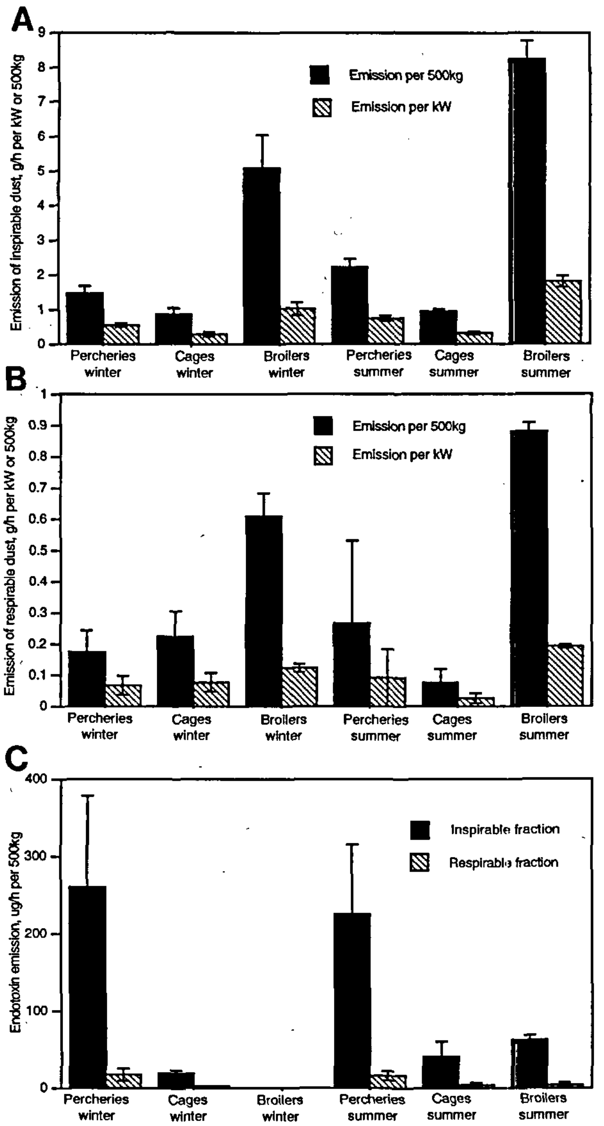
Table 3. *Mean (± SE,* n = *4) ventilation rate in three types of poultry house calculated from a mass balance of carbon dioxide*

	Mean ventilation rate	
	m^3/h per 500 kg live body weight	m^3/h pen kW
Percheries		
Winter	749 ± 320*	269 ± 99*
Summer	1473 ± 96	499 ± 33
Cages		
Winter	445 ± 21	149 ± 13
Summer	1120 ± 154	383 ± 52
Broilers		
Winter	454 ± 74	92 ± 14
Summer	941 ± 145	207 ± 36

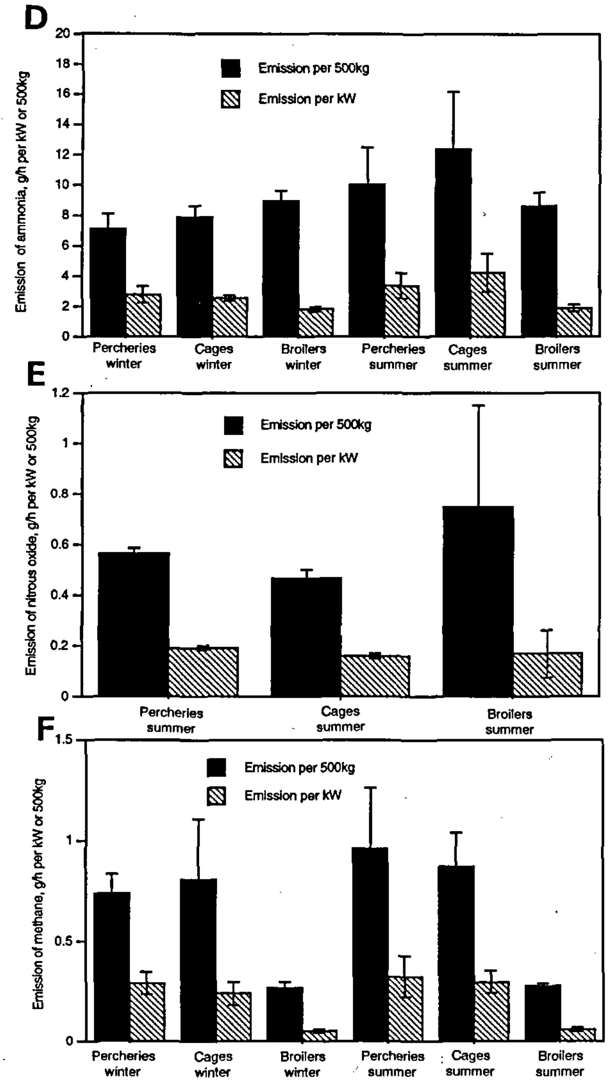
*Standard error of the mean.

poultry house. They are similar to those reported by Groenestein *et al.* (1993) and Groot Koerkamp (1994) and are much higher per unit of live body weight than emission rates of ammonia from other farm species. Wastes from farm animals are by far the largest anthropogenic source of ammonia emitted to the atmosphere (ECETOC, 1994), but within that category, housed poultry are a modest contributor (Jarvis and Pain, 1990).

The measurements of the emission rates of the



Figures 7A–F. *Emission rates of aerial pollutants from 24 h measurements during winter and summer. A: inspirable dust; B: respirable dust; C: endotoxin; D: ammonia; E: nitrous oxide; and F: methane.*



Figures 7D–F. *See previous caption.*

other aerial pollutants (gaseous methane and nitrous oxide, particulate dusts and endotoxin) appear to be novel. Atmospheric emissions of methane are of concern because of their potential contribution to global warming; there is much interest in quantifying emissions from a variety of industrial, biological and agricultural sources (Williams, 1989; Van Amstel, 1993). Amongst the farm species, cattle are the most potent source with an emission rate of methane per unit of body weight that is typically 10 times the rates observed for hens in this survey. Nitrous oxide is also implicated in climate change, not only because of its radiative forcing power but also because it harms the stratospheric ozone layer. Our measurements of the emission rates of this gas from poultry houses show the relative unimportance of this anthropogenic source. Although data on emissions of endotoxin are given here, there is little evidence to date that these emissions pose a significant hazard to people living close to livestock farms. Finally, the emission rates of aerial dust may help to explain the importance of this pollutant in complaints of malodours from livestock buildings, especially broiler houses (O'Neill and Phillips, 1992). Dust particles may act as carriers of specific odorants of which over 100 chemical species have been identified in the air of animal houses (O'Neill and Phillips, 1992). Hammond *et al.* (1981) concluded that odorants are concentrated on dust particles and may be perceived as a more intense odour than odorants in the gas phase, because of the selective deposition of the former in the nasal passages. However, olfactometric studies by Williams (1989) showed that dust extraction in hen houses decreased odour concentration only by $\approx 10\%$. Many poultry units comprise a number of buildings on one site, perhaps totalling up to 100 000 birds (≈ 200 t at slaughter weight). Given dust emission rates of up to 8 g/h per 500 kg body weight, then there should be little surprise if complaints of malodours arise amongst neighbours living within 1 to 2 km of the farm given total emission rates of *circa* 3·2 kg/h. Information on dust emission rates may also be helpful in assessing the likely environmental impact of new units when planning permission is sought.

These findings support the general consensus that air quality in, and emission rates of, aerial pollutants from poultry houses are unsatisfactory according to a variety of criteria (Wathes, 1994). There is an equally pressing need to identify abatement and control techniques that are technically feasible, environmentally acceptable and economically viable. It is unlikely that any one technique will provide the universal cure: instead a number of separate measures taken together offer the best prospect (Wathes, 1994). For example, the concentration of aerial dust can be reduced by spraying intermittently a fine mist of rapeseed oil (Takai *et al.*, 1993) while daily or thrice-weekly removal of droppings from cage units to closed storage systems may lower the concentration of gaseous ammonia (Groot Koerkamp, 1994). Historically, the concentration of aerial pollutants has been reduced by raising the ventilation rate to dilute the level of contaminants. This practice suffers from several weaknesses that now preclude its use. Firstly, it may compromise the control of temperature in poultry houses where the financial penalties of departure from the productivity optimum may be severe (Charles, 1994). Secondly, discharge of gaseous and other pollutants to the atmosphere may be harmful to the local and global environment, and is thus unacceptable. Prevention of the formation and release of aerial pollutants will always be the most attractive strategy, as with many industrial pollutants.

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