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PPC bioaerosols (dust and particulates) potentially emanating from intensive agriculture and potential effects on human health

Science Report – SC040021/SR4

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Steve Killeen

Head of Science

Executive summary

In recent decades, agriculture has undergone dramatic changes. Small mixed-production farming operations that produced several different crops and utilised pigs or poultry to consume by-products or excess grain have given way to large farrow-to-finish units dedicated to swine production or large scale factories dedicated to broiler production or the housing of laying hens. The global poultry population has quadrupled to 17.8 billion birds and the swine population has trebled to 2 billion since the early 1960s, with the advent of intensive farming.

Some elements of intensive farming of pig and poultry are now regulated by the Environment Agency under the Integrated Pollution Prevention Control (IPPC) regime. One aspect of that regulation is ensuring that bioaerosols produced by intensive farming activities are managed and controlled so that adverse human health effects are not caused. This is particularly important for people who may live near to these types of facility.

We know the nature of the changes in the style of livestock farming has led to health problems for both workers involved in intensive livestock production and the animals themselves. There have also been growing concerns about the effect that bioaerosols emitted from intensive farming facilities may have on people living close by. The main aim of this literature review is to move towards being able to answer the question 'Am I at risk of ill health from environmental exposure to bioaerosols from intensive agricultural activities?'

In the first part of this review, bioaerosols are defined and their content discussed. We found that the majority of bioaerosol studies examined dust concentration in the air, as well as the total bacterial, fungal and endotoxin concentrations within the dust. A few studies identified the types of bacteria and fungi within the bioaerosol. The detection methods commonly used to sample the dust and microbial content of bioaerosols in pig and poultry buildings were reviewed.

The way the animals were kept (housing conditions) were found to greatly influence bioaerosol concentrations. The effects of feed type and waste management systems on bioaerosol formation have been studied, as were differences in the type of ventilation systems in pig buildings and poultry houses. We found that the use of dry feed and the presence of dry faecal waste led to raised bioaerosol levels. Seasonal changes to ventilation were also found to affect bioaerosol concentrations in animal buildings as well as concentrations emitted from those buildings.

For both pigs and poultry, increased activity, whether due to housing conditions, time of day, stage of growth or handling, corresponded to raised bioaerosol levels. Increased stock density was also a key issue in raised bioaerosol concentrations.

This review has highlighted a variety of control strategies that can be used to reduce dust levels in livestock buildings. The research into the efficacy of each of these methods has been summarised, but there is little evidence that respiratory protective equipment is widely used to reduce exposure to bioaerosols.

There is considerable evidence that working conditions in pig and poultry buildings do have an impact on workers' respiratory health. The effect of various activities undertaken by pig and poultry workers was examined and it was found that the more dust disturbed by a task, whether by the worker or increased animal activity, the greater the exposure of the worker and the greater likelihood that the worker would exhibit symptoms.

In comparison to the large number of studies of bioaerosols *within* pig buildings and poultry houses, very few studies on the emission of bioaerosols *from* such facilities (including studies of their content and of the distance travelled from the building) were found. There is some information in the literature to demonstrate the potential for bioaerosol emissions from intensive farming activities to raise ambient bioaerosol levels some distance downwind. However, the effect of these emissions on the overall atmospheric bioaerosol burden has not been defined.

Although it is clear that bioaerosol emissions from intensive farming activities may increase the concentration of bioaerosols inhaled by those living close to such facilities, at present there is insufficient evidence to assess the potential for this to result in an increased risk of respiratory ill health (or other adverse health effect). Further information is also required on which sections of the production processes make the greatest contribution to bioaerosol emissions. This would assist in applying controls at key points in time or at specific locations. More controls need to be put in place to ensure that detected microorganisms and endotoxins are actually from the livestock buildings and not from the wider environment. The way bioaerosols are distributed once in the wider environment also needs further investigation, as does the role of the weather (wind velocity, humidity and temperature) and obstacles such as buildings. Correlations between bioaerosol concentration, particulate size and distance travelled also need to be fully characterised.

This review has highlighted factors that we know to increase bioaerosol emissions such as increased animal activity, building type, ventilation rates, housing conditions etc. However, there still remains considerable areas of uncertainty in our knowledge and understanding and until the further work identified has been carried out generic guidance is difficult to generate.

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1. Introduction

1.1 Background

Under the Integrated Pollution Prevention and Control (IPPC) regime the Environment Agency is responsible for regulating the larger intensive agriculture activities including pig and poultry farming.

The IPPC system applies an integrated environmental approach to the regulation of certain commercial activities. This means that emissions to air, water (including discharges to sewer) and land, plus a range of other environmental effects, must be considered together. It also means that regulators must set permit conditions so as to achieve a high level of protection for the environment as a whole. These conditions are based on the use of the “Best Available Techniques” (BAT), which balances the costs to the operator against the benefits to the environment (Defra 2005).

Pig and poultry farmers must apply to us for a permit to operate if their livestock capacity exceeds:

- 750 sows
- 2,000 production pigs over 30kg
- 40,000 poultry (includes chickens, layers, pullets, turkeys, ducks and guinea fowl)

Under the IPPC regime we have a responsibility for dealing with issues related to potential adverse effects on human health from the intensive agriculture activities we regulate. One area where we have limited knowledge at present is that of exposure of members of the public to bioaerosols or particulates from intensive agriculture (specifically that involving pigs and poultry) and any potential health effects from those activities. On a large scale these types of activity have the potential to create dust and bioaerosols. Workers will be at greatest risk of exposure, but fugitive bioaerosol emissions may also be capable of being dispersed beyond the site boundary and potentially adversely affect the health of those living nearby.

In terms of health protection we need to understand the potential impact of emissions from intensive agriculture activities in relation to other bioaerosol generating activities such as composting. This report consists of a critical review of published literature on bioaerosols and dust from intensive livestock agriculture (pigs and poultry) and potential human health effects.

1.2 Aims and objectives

The main aim of this review was to undertake a literature review of published data on bioaerosols, dust and particulates from intensive agriculture, with a specific focus on diseases or other health effects caused by bioaerosols from intensive farming of pigs and poultry. This will enable us to move forward in answering the question:

- Am I at risk of ill health from environmental exposure to bioaerosols from intensive agricultural activities?

Specifically this review has focused on an overall objective of identifying:

- numbers and species of micro-organisms comprising bioaerosols associated with agricultural operations, specifically intensive pig and poultry production
- methods used to detect, collect, and enumerate bioaerosols in agriculture, including total and culturable micro-organisms, endotoxins and molecular based estimates
- differences (where reported) associated with the growing/rearing cycle of domestic livestock such as poultry and pigs
- effects of housing conditions, such as litter type and feed delivery methods
- types of buildings in which animals are reared, including effects of ventilation or air handling, and how these affect dispersal of bioaerosol from the buildings
- occupational exposure during different types of activities of swine and poultry workers
- use and effectiveness of dust and particulate controls
- bioaerosol emissions from confinement buildings
- key findings & conclusions

1.3 Intensification of agriculture

In 1713, Ramazzini noted that farmers commonly suffer respiratory illness as a result of exposure to dust in their work environment (Donham 1986). Nearly 300 years later, this fact has not changed, with increasing numbers of farmers suffering symptoms following dramatic changes in agricultural practice. Historically, respiratory disease has been associated with the grain dust generated during harvesting and feed manufacture, as well as the dust generated during cotton production. In recent decades, similar symptoms have been seen in farmers involved in the intensive farming of pigs and poultry. Small mixed-production farming operations that produced several different crops and utilised swine or poultry to consume by-products or excess grain have given way to large farrow-to-finish units that are dedicated to swine production or factories dedicated to broiler production or the housing of laying hens.

Starting in the 1950s in Western Europe and in the 1960s in North America, many farmers enlarged, intensified and specialised their livestock production techniques. Since 1961, the worldwide population of livestock has increased by 38 per cent, reaching 4.3 billion animals in 2006. The global poultry population has quadrupled in that time, to 17.8 billion birds, and the number of pigs has roughly trebled to 2 billion (Vidal 2006). In order to accommodate these large numbers of animals and poultry, farmers now use semi-automated structures known as confinement buildings. These structures allow the producer to raise a large number of animals in a relatively small space, with protection from the outdoor environment and minimum work force costs. Confinement buildings share the following components:

- an enclosed structure accommodating a large number of animals in a relatively small space
- a ventilation system
- a system for watering the livestock

- a system for feeding the livestock
- a system for handling the animal waste

As a consequence of this intensification, by increasing the density of animals and holding them in enclosed buildings, the concentrations of airborne dust and microorganisms have increased, in the form of bioaerosols.

1.4 Bioaerosols and human health

Bioaerosols are a major component of the particulate matter found in confinement buildings. They are simply defined as particles of biological origin that are suspended in the air and are often referred to as organic dust. In general, bioaerosols primarily consist of pathogenic or non-pathogenic, live or dead bacteria and fungi, high molecular weight allergens, bacterial endotoxins, mycotoxins, peptidoglycans, β -(1-3)-glucans, pollen and plant fibres (Douwes *et al.* 2003). A list of bioaerosol components is shown in Table 1.1.

Table 1.1 Components of bioaerosols found in confinement buildings

Non-Microbial	Microbial
Plant materials	Microorganisms
Proteins	Bacteria
Starches	Bacterial spores
Carbohydrates	Fungi
Feed additives	Fungal spores
Vitamins	Viruses
Minerals	
Amino acids	Products of bacteria
Antibiotics	Endotoxins
	Exotoxins
Mammalian cell debris	Peptidoglycans
Aeroallergens	Products of fungi
Plant pollens	Conidia and microconidia
Mite faecal allergens	Hyphal fragments
Arthropod debris	Mycotoxins
	Glucans

Source: Thorne (1994)

Over the past few decades, interest in bioaerosols has grown. This has largely been due to the recognition that exposure to biological agents in both occupational and residential indoor environments is associated with a wide range of adverse health effects. In the context of intensive pig and poultry farming, there are three main sources or airborne microorganisms:

- animals
- feed
- bedding and excreta

Firstly, animals themselves continuously shed rafts of skin scales, some of which will carry aerobic and anaerobic commensal bacteria (Noble 1975; Benediktsdottir and Hambraeus 1982). Diseased animals also shed specific pathogens in exhaled breath, urine, faeces and secretions. Secondly, deep litter or slurry stores provide an attractive growth medium for some microorganisms, which are liberated following agitation during bedding down or emptying of under floor pits. Thirdly, animal feed is a powerful source of airborne dust (Curtis and Drummond 1982), especially during distribution, and can also act a reservoir for fungi. Other sources of airborne microorganisms, such as workers, wild birds and rodents, are usually minor, but these sources can, in certain circumstances, act as reservoirs and shedders of pathogens (Sellers *et al.* 1970)

The dust in swine and poultry buildings is primarily organic (of a biological nature). Dust is present in barns in a wide range of sizes and is measured in units called ‘micrometres’ or ‘microns’. A micrometre (μm) is a unit of length equal to 0.001mm. Depending on its size, dust can be filtered out in the upper part of the human respiratory system, including the nose and pharynx, or it can travel deep into the lungs and become embedded in the outermost lung tissue.

Dust particles in indoor environments are generally defined as total, inhalable or respirable, depending on the size of the dust particle and its potential impact on the respiratory system. Total dust refers to all airborne particulates. The visible dust that is present on penning material and on the floors and walls of pig barns tends to be made up of larger particulates. Due to their size and weight, these larger dust particles tend to settle out of the air first.

Typically, dust particulates that are $<100\mu\text{m}$ in size are efficiently filtered out by the human nose and pharynx; these are referred to as inhalable dust. However, airborne particles that are $<10\mu\text{m}$ in diameter are easily trapped in the upper and lower airways and are referred to as respirable dust. Mid-sized respirable particles (1– $5\mu\text{m}$) are more likely to settle in the small airways (West 1998). Particles in this size range are small enough to stay suspended in the air and therefore have all the properties of an aerosol; it is particles in this size range that constitute a bioaerosol. Most microorganisms in animal houses are attached to dust particles, as confirmed in studies by Hinz and Krause (1987). These authors also compared the numbers of dust particles and microbes associated with animal production. They found that, on average, the number of dust particles was 47 times greater than the number of microbes in swine buildings and 78 times greater than the number of microbes in poultry houses. The size of the dust particles was in the range of 3– $10\mu\text{m}$.

There are a variety of other factors associated with bioaerosols that can affect the health of both humans and animals. For example, gases in the swine building environment and the poultry-rearing industry have been identified as a potential human health risk. These gases mainly consist of ammonia, carbon dioxide and hydrogen sulphide.

Ammonia gas is produced from the breakdown of manure and urine (although less is produced from the storage of liquid manure). Ammonia is a weak base that is also highly water soluble and can dissolve into the mucous membranes of the eyes, nose and throat (including the upper respiratory system) where it reacts to form hydroxide which then attacks the tissues. Air sampling studies conducted in turkey confinement buildings have found ammonia at concentrations ranging from 35–100ppm (Andersen *et al.* 1968; Cravens *et al.* 1981; Mulhausen *et al.* 1987).

Hydrogen sulphide is a by-product of the anaerobic breakdown of manure by bacteria. It is normally present at low levels but can attain lethal concentrations when manure is

agitated. Carbon dioxide is present in the swine building primarily as a by-product of pig respiration. Levels of carbon dioxide are used therefore as a measure of building air quality and the adequacy of the building's ventilation system.

Ammonia and hydrogen sulphide gases may sorb on to dust particles and thus contribute to odours as they are discharged into the environment from the ventilation systems of pig housing buildings (Bundy and Hazen 1973, Janni *et al.* 1984). There is concern that these compounds may affect the respiratory health of people living close to livestock enterprises. According to the UK Department for Environment, Food and Rural Affairs (Defra), emissions from pig confinement buildings are estimated at 19,000 tonnes of ammonia per year (Chambers *et al.* 2002). This accounts for 9 per cent of annual ammonia emissions from the UK, whereas poultry houses account for 14 per cent of the annual UK ammonia emissions.

1.5 Structure of this report

This report consists of 9 sections as follows:

- Section 1 – Introduction
- Section 2 – Microbial content of bioaerosols and intensive agriculture
- Section 3 – Bioaerosol sampling methods
- Section 4 – Effect of growth stage, livestock activity & density on bioaerosol emissions
- Section 5 – Effect of ventilation & housing conditions on bioaerosol emissions
- Section 6 – Occupational exposure & work activity of swine and poultry workers
- Section 7 – Use and effectiveness of dust and particulate controls
- Section 8 - Bioaerosol emissions from livestock buildings
- Section 9 – Summary & conclusions

2 Microbial content of bioaerosols and intensive agriculture

Common bioaerosol components were listed in Table 1.1, comprising microbial and non-microbial in origin. This section focuses on the microbial content of bioaerosols: bacteria, fungi and their products. Viruses and their products have not been looked at in detail.

2.1 Bacteria and bacterial products in bioaerosols

2.1.1 Bacteria in bioaerosols

Many species of microorganisms have been isolated from poultry and swine buildings. However, variations in geographical location, housing conditions and feed ingredients can impact on the gastric flora of animals and, in turn, on the microbial content of bioaerosols. Genera of bacteria found in air samples from swine buildings include the Gram-negative organisms ¹*Enterobacter*, *Acinetobacter*, *Moraxella*, *Pseudomonas* and *Escherichia coli* and the Gram-positive organisms² *Enterococcus*, *Staphylococcus*, *Streptococcus*, *Bacillus*, *Aerococcus* and *Micrococcus* (Kiehaefer *et al.* 1995; Cormier *et al.* 1990). Some authors found that the majority of bacteria in bioaerosols are Gram-positive organisms (especially Enterococci), with less than 25 per cent being Gram-negative (Clark *et al.* 1983; Heederik *et al.* 1991).

Dutkiewicz *et al.* (1994) determined that swine buildings contain very large concentrations of airborne mesophilic bacteria (which thrive at moderate temperatures). The predominant family was Gram-positive *Corynebacteria*, mostly of the genera *Arthrobacter* and *Corynebacterium*. In swine buildings, this family comprised around 58 per cent of the total bacteria. The concentrations of non-culturable aerobic and anaerobic bacteria in swine barns are known to be 10- to 100-fold higher than the culturable organisms (Lange *et al.* 1997; Heederik *et al.* 2002). Lenhart *et al.* (1982) reported that the most predominant genera of bacteria in a poultry processing plant were the Gram-positive *Bacillus sp.*, *Corynebacterium sp.*, *Micrococcus sp.* and *Staphylococcus sp.* and the Gram-negative *Acinetobacter sp.*, *Alcaligenes sp.*, *Escherichia coli*, *Hafnia alvei* and *Proteus mirabilis*. Vucemilo *et al.* (2005) found that the predominant microorganisms in a broiler house changed during the final weeks of fattening. However, they reported that *Serratia sp.*, *Pseudomonas sp.*, *Pantoea sp.* and *Micrococcus sp.* were the predominant bacteria.

¹ Gram negative bacteria – bacteria are considered to be gram-negative because of their characteristic staining properties under the microscope, where they either do not stain or are decolourised by alcohol during Gram's method of staining. This is a primary characteristic of bacteria that have a cell wall composed of a thin layer of peptidoglycan covered by an outer membrane of lipoprotein and lipopolysaccharide containing endotoxin.

² Gram positive bacteria – types of bacteria that do take up Gram's Stain. This is a primary characteristic of bacteria whose cell wall is composed of a thick layer of peptidoglycan containing teichoic and lipoteichoic acid complexed to the peptidoglycan.

2.1.2 Endotoxins in bioaerosols

Endotoxins are a constituent of the outer membrane of the cell wall of Gram-negative bacteria and are almost always present in organic dusts, such as the dusts in swine confinement buildings and poultry houses. The half-lives of Gram-negative bacteria in an airborne state are generally short (Heidelberg *et al.* 1997). However, endotoxic activity persists even after the death of these bacteria, leading to an accumulation of endotoxin in the dust, both on stable surfaces and in stable air (Zucker *et al.* 2000). Inhalation of organic dust containing endotoxin has been associated with transient as well as chronic lung function impairment in humans (Rylander 1994; Lacey and Dutkiewicz 1994).

2.2 Fungi and fungal products in bioaerosols

The most commonly found fungi are the mould genera *Aspergillus*, *Scopulariopsis*, *Penicillium*, *Geotrichum*, *Mucor* and *Fusarium*. Yeasts found in the swine environment include *Candida*, *Cryptococcus*, *Toropsis*, *Trichospora*, *Rhodotorula* and *Hansenula* (Thorne 1994). Rautiala *et al.* (2003) reported that in their studies, as well as in others, the predominant fungi were *Aspergillus sp.*, *Penicillium sp.*, *Scopulariopsis sp.* and yeasts.

Vucemilo *et al.* (2005) found that yeasts predominated throughout their study of poultry houses, but also reported the presence of *Aspergillus flaviceps*, *Rhizopus sp.* and *Mucor sp.*

2.3 Summary - comparing pig and poultry buildings - microbial content of bioaerosols

Hinz and Krause (1987) compared the microbial content of bioaerosols in poultry houses with that in swine buildings. Their findings are summarised in Figure 2.1 (Hinz and Krause, 1987). These authors noted that there was a wider spectrum of both fungal and bacterial species in poultry production compared to the range of species associated with swine buildings. The main genera of bacteria common to both types of confinement building were *Bacillus sp.*, *Staphylococcus sp.* and *Streptococci*. The common genera of fungi were *Scopulariopsis*, *Cladosporia* and *Mucor sp.*

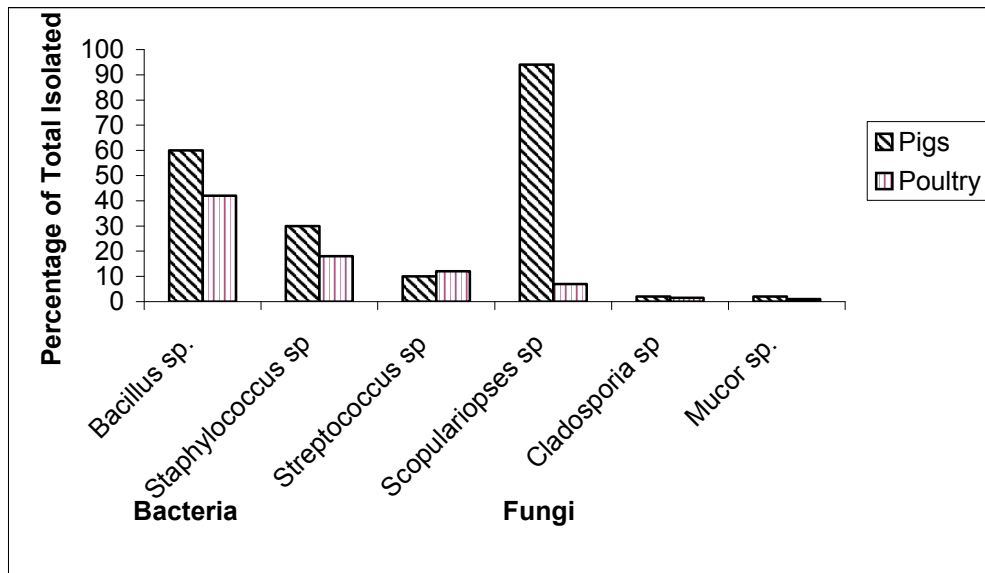


Figure 2.1 Comparison of bacteria and fungi (as a percentage of totals isolated) in confinement buildings of pigs and poultry

3 Bioaerosol sampling methods

A review of the literature on bioaerosols in intensive farming from 1960 to the present has highlighted not only the development of certain sampling methods but also the wide variety of techniques that are used. Still to this day, there does not appear to be any standardisation in the sampling methods used by different research groups.

Prior to the development of modern air sampling equipment, aerosolised dust was examined by light microscopy to determine its constituents and the particle size (Lippman 1983). Settled dust was also analysed for protein content (Conway 1950), microbial content (Trehaff and Marcus-Jones 1982) and endotoxins (Thedell *et al.* 1980). More recently, however, impaction, impingement and filtration have become the most widely used techniques for assessing both dust and airborne microbial load.

3.1 Sampling organic dusts

A review of the available literature revealed that multistage impactors have been used to measure the distribution of aerosol mass in the swine (Donham and Gustafsson 1982; Donham *et al.* 1984, 1986a, b; Burge *et al.* 1987; Rappaport 1991) and poultry (Cook 1987; Enarson *et al.* 1985; Rappaport 1991) industries. Multistage impactors can be used to determine the mass in each aerodynamic size range and the distribution parameters; a typical example is the Andersen sampler described below. However, most evaluations of organic dust have measured either total dust or the respirable mass fraction using filtration methods (Donham and Gustafsson 1982; Donham *et al.* 1977, 1984, 1986a, b; Thedall *et al.* 1980; Cravens *et al.* 1981; Jones *et al.* 1984; Attwood *et al.* 1986; Carpenter *et al.* 1986; Butera *et al.* 1991; Senthilselvan *et al.* 1997; Simpson *et al.* 1999; Chang *et al.* 2001a; Spaan *et al.* 2006).

Both area and personal sampling devices have been used to evaluate total dust levels. Jacobs (1994) and Donham (1986) claimed that personal sampling, using open-faced 35mm cassettes with a personal air pump delivering 1–2 litres/minute, is used most frequently for the analysis of total dust. Although close-faced cassettes have been used, they tend to underestimate the total dust concentration. Agreement between the two types of cassette is dependent on its orientation and on environmental variations such as wind velocity (Beaulieu 1980). Standardisation is needed regarding the use of open- or closed-faced cassettes, filter type, and filter handling and evaluation to allow valid comparisons to be made both within and between environments with organic dust (Donham 1986; Jacobs 1994). This recommendation was based on the observation that size-selective samplers do not account for factors in the lung that can affect particle characteristics, whereas total dust measurements are accurate indicators of dust levels at ambient environmental conditions and more accurately reflect worker exposure (Jacobs 1994).

3.2 Sampling respirable dust

Jacobs (1994) suggested that the most commonly used respirable sampling device is the 10mm nylon cyclone (Clark *et al.* 1983; Donham *et al.* 1984, 1986b; Jones *et al.* 1984; Iversen and Dahl 1994). This is an inertial sampling device that is usually used to sample in the breathing zone and classifies particles according to a fixed size and flow rate (see Figure 3.1). However, respirable dust samples may cause the effects of organic dust in the lung to be underestimated because of the solubility of the dust in non-gas exchange regions in the lung (Donham *et al.* 1986b).

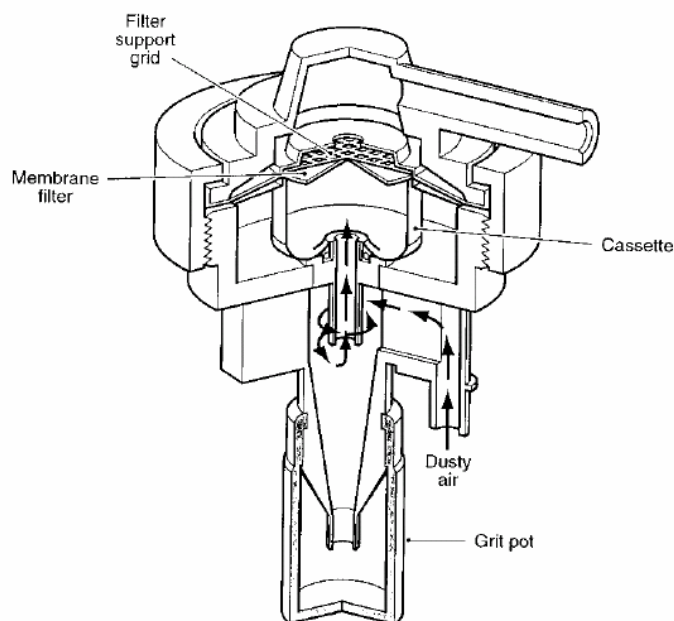


Figure 3.1 Cyclone sampler

This device acts to separate larger particles from respirable particles, which are then collected onto a filter.

Donham *et al.* (1986b) compared an Andersen non-viable cascade impactor and personal cyclone separators in swine confinement buildings. They concluded that the personal cyclone separator was not a reliable method for measuring respirable dust within agricultural settings. This followed their discovery that a combination of both microscopic sizing and a cascade impactor produced significantly higher respirable fractions than a 10mm cyclone.

The Andersen non-viable sampler is a type of cascade impactor and has been used in several studies on agricultural dusts with no major reported problems (Donham *et al.* 1984, 1986b; Jones *et al.* 1984). However, unlike the viable six-stage Andersen sampler described below for microbial detection, the non-viable Andersen sampler uses filters that can prove difficult to weigh because of their large size. Filter sampling may also be adapted to measure respirable dust (Eduard and Heederik 1998) and the same equipment can be used for total organic dust analysis by utilising varying filter sizes. An open-faced cassette can be loaded with a 47mm filter to capture total dust and then loaded with a 37mm membrane filter to collect respirable dust.

A sampling device developed by the Institute of Occupational Medicine (IOM) and known as an IOM sampler can collect particles over a range of sizes (Mark and Vincent 1986). The IOM personal inhalable sampler comprises a conductive plastic sampling head that collects airborne particles onto the surface of a filter and is housed in a reusable 25mm filter cassette (Figure 3.2). When attached to a personal sampling pump operating at 2 litres/minute and clipped near a worker's breathing zone, the IOM effectively traps particles up to 100µm in aerodynamic diameter and closely simulates the manner in which airborne workplace particles are inhaled through the nose and mouth. IOM samplers are recommended samplers for workplace measurement of total inhalable dust. This involves weighing the cassette and filter as a single unit before and after sampling (HSE 2000).



Figure 3.2 IOM personal sampler

The IOM sampler has been utilised for sampling in a wide range of occupational situations, both as a personal sampler and as an area sampler, but has seemingly not been widely used for air sampling in swine and poultry buildings. Takai *et al.* (1998) reported using IOM samplers to collect inhalable dust fractions whilst surveying airborne dust emissions in swine and poultry buildings. In 1999, Simpson *et al.* utilised IOM samplers to examine individual exposure to organic dust and endotoxins.

The IOM sampler has the advantage of being small and can be attached to workers' clothing. It is operated by a pump worn on the worker's belt and therefore doesn't restrict worker mobility. As with other filtration methods, the type of filter material can influence the performance of the IOM filter. Saleh *et al.* (2005) utilised IOM samplers for the analysis of bioaerosols in broiler houses, and used glass fibre filters to detect respirable dust and polycarbonate filters to detect bacteria.

There are a variety of filtration air samplers that can be used solely for large-scale area sampling. A typical example would be a Partisol sampler (Figure 3.3). These are static samplers (models 2000 and 2005) designed to collect PM₁₀ (particulate matter less than 10µm in size) onto 47mm filters at a flow rate of 16.7 litres/minute, giving a total volume of 1m³/hour. Partisol samplers are commonly used for air pollution monitoring and, because of the potential to cross-reference sampling methods, they have been used to monitor compost bioaerosols. The Partisol 2000 and 2005 samplers operate in the same way, but the 2005 model includes an automatic filter change mechanism, which allows timed sequential sampling and is important in situations where the sample filters may become overloaded. The samplers also have an integrated vacuum pump and are powered by either heavy-duty batteries or portable generators.



Figure 3.3 Partisol sampler

3.3 Microbial detection methods

There are three standard techniques for the analysis of airborne microorganisms:

- impaction (microorganisms are collected directly onto solid culture medium)
- liquid impingement (microorganisms are collected in a liquid media) and
- air filtration methods (microorganisms are collected on a filter)

3.3.1 Impaction methods

Impaction is the most favoured technique for static area sampling, such as used inside livestock buildings. The six-stage Andersen viable cascade impactor (Figure 3.4) is the most commonly used instrument for examining poultry and swine buildings (Kotula and Kinner 1964; Avens *et al.* 1975a, b; Curtis *et al.* 1975; Lenhart *et al.* 1982; Clark *et al.* 1983; Jones *et al.* 1984; Donham *et al.* 1986a; Lutgring *et al.* 1997; Whyte *et al.* 2001; Rautiala *et al.* 2003; Chinivasagam and Blackall 2005).



Figure 3.4 Andersen sampler showing six stages

This sampler collects airborne particles via impaction onto the surface of agar plates, which are placed under six stacked sieve plates, each with 400 holes of a defined size. These holes get progressively smaller from top to bottom, so that collected particles are separated into six size ranges. Stages 1 and 2 collect particles that are $>7\mu\text{m}$ in aerodynamic diameter, equating to nasal deposition; stages 3 and 4 collect particles $3\text{--}7\mu\text{m}$ in diameter, equating to bronchial deposition; and stages 5 and 6 collect particles $<3\mu\text{m}$ in diameter, equating to alveolar deposition. Suction for Andersen samplers is provided by generator-powered vacuum pumps run at the required air flow rate. The single stage version is recommended in the Composting Association guidelines for bioaerosol monitoring (Composting Association 1999). In many studies, the six stage version has also successfully been used to obtain particle size data. However, when measuring agricultural dusts, the researcher is limited to short sampling periods and personal sampling is not practical. The Andersen sampler has also served as a reference sampler for evaluating other sampling devices (Chatigny *et al.* 1989; Zimmerman 1987).

3.3.2 Liquid impingement methods

All-glass impingers (AGI) have also been widely used in studies of swine and poultry buildings (Olenchock *et al.* 1982; Rask-Andersen *et al.* 1989; Crook *et al.* 1991; Dutkiewicz *et al.* 1994; Nielsen and Breum 1995, Kollner and Heller 2005). AGIs have the advantage that they are less selective than Andersen impactors, as a single sample can be serially diluted and cultured on a multitude of growth media. They can also be operated over longer periods of time. However, the sampling period for the AGIs should not exceed 60 minutes due to the continuous loss of sampling fluid (Zucker *et al.* 2000). An example of an all-glass-impinger is shown in Figure 3.5.



Figure 3.5 An all-glass-impinger

3.3.3 Filtration methods

Filtration followed by elution into a liquid medium is also widely used for the detection of microorganisms in dust (Elliot *et al.* 1976; Attwood *et al.* 1987; Martens *et al.* 2001; and others). It is simple and relatively inexpensive compared to other sampling methods (Predicala *et al.* 2002). A filtration system can also be operated for long periods and the collected samples can be diluted and analysed using a wide range of growth media. The sample collection efficiency depends on the type of filter used, and a wide range of filtration air samplers of various sizes and using a variety of filter materials are on the market. Filtration can be used for both area and personal monitoring of bioaerosols. IOMs and Partisol samplers are typical filtration methods and can be used not only to examine respirable dust but also to detect microbial and endotoxin concentrations. There are a number of advantages of using filtration to monitor bioaerosols, including longer sampling periods and the ability to measure both viable and non-viable microorganisms. However, the process of filtration underestimates viable microorganisms, because the trauma of rapid flow rates, dehydration and collision destroys the viability of some species of microorganisms (Burge *et al.* 1987).

3.3.4 Comparing detection methods

Thorne *et al.* (1992) compared the performance of Andersen impactors, AGIs and filtration in the parallel sampling of swine buildings. They found that the Andersen sampler had a poor data yield because of overloading and demonstrated weak correlation with the AGI. Conversely, the AGI and filtration methods generated sufficient numbers of valid data points (90 per cent), yielded high interclass reliabilities and were highly correlated with each other. Thorne *et al.* (1992) concluded that only the AGI and filtration methods were suitable for assessing bacteria. However, they also found that the Andersen impactor was the preferred method for detecting enteric (intestinal) bacteria. For the analysis of fungi, all methods of sampling were successful but the AGI measured significantly higher concentrations than the Andersen impactor. Lundholm (1982) reported that an AGI is less accurate than impaction at quantifying bacteria-containing bioaerosols if the bacteria are largely single-cell particles. However, when bacteria aggregate, higher bacterial counts are found with an AGI due to the break up of bacterial clusters (Jacobs 1994).

Predicala *et al.* (2002) compared the performance of open-faced filter cassettes and six-stage Andersen impactors for assessing bioaerosols in swine buildings. Total and respirable colony-forming units (CFUs) of bacteria were examined and a comparison of the concentrations obtained by the two samplers showed significant differences. Filtration recorded significantly lower total CFU concentrations, underestimating the total CFU concentration by about 23 per cent compared to impaction. Jensen *et al.* (1992) observed similar results and attributed this to the possible desiccation of the microorganisms on the membrane filter during sampling.

Zucker *et al.* (2000) compared the use of filtration and impingement for sampling airborne endotoxins in swine and poultry buildings. The results from four consecutive AGI 30 impingers were compared with those from a PGP dust sampling system (Strohlein GmbH, Germany). This system contained an 8µm isopore PTFE (polytetrafluoroethylene) filter and was run for the same length of time as the four impingers. The presence of endotoxin was tested directly on the AGI liquid, whereas the filters were washed for two hours prior to analysis. Zucker *et al.* (2000) found a good correlation between the two methods but reported that the AGIs had a higher collection efficiency than the filtration system, especially in animal houses with high concentrations of airborne endotoxin. Milton *et al.* (1990) suggested that there was potential for some of the endotoxins to remain on the filter during the extraction procedure. This problem would not occur with impingement, for either airborne microorganisms or endotoxin, since the collection fluid could be investigated without any further treatment.

3.3.5 Laboratory analysis

After sample collection, colonies of bacteria or fungi are grown on selective agar at a defined temperature over a 3–7 day period. Colonies are counted manually or with the aid of image analysis techniques. Counting of culturable microorganisms has some drawbacks, including poor reproducibility and that the chosen media and temperature may favour the growth of certain species. In addition, dead microorganisms, cell debris and microbial components are not detected, although they may also have toxic and/or allergenic properties. On the other hand, counting culturable microorganisms is potentially a very sensitive technique and many different species can be identified. Douwes *et al.* (2003) felt that traditionally-used culture methods have proven to be of limited use for quantitative exposure assessment. Culture-based techniques thus usually provide qualitative rather than quantitative data. This data can, however, be important in risk assessment, since not all fungal and bacterial species pose the same

hazard. All the reported studies of the microbial content on aerosols in swine or poultry confinement buildings have used culture on agar as the means of detection.

Non-culture based methods enumerate organisms without regard to viability and have been used to analyse the bioaerosols associated with occupational settings such as composting and wood cutting. Sampling of non-culturable bioaerosols generally involves air filtration or liquid impinger methods. Microorganisms can be stained with a fluorochrome, such as acridine orange, and counted with an epifluorescence microscope (Thorne *et al.* 1994). Possibilities for classifying microorganisms taxonomically are limited because little structure can be observed. Electron microscopy (EM) or scanning EM can also be used and allows better determination (Eduard *et al.* 1988; Karlson and Malmberg 1989). Simple light microscopy may also be used to count microorganisms, but this counting is based on morphological recognition and may result in severe inaccuracies due to debris and human error. The use of methods such as polymerase chain reaction (PCR)-based techniques and immunoassays has opened new avenues for detection and speciation regardless of whether the organisms are culturable. PCR is used to amplify small quantities of target DNA, typically by 10^6 – 10^{10} times, in order to determine the presence of specific microorganisms in a qualitative or quantitative manner.

3.3.6 Assessment methods for microbial constituents

Constituents or metabolites of microorganisms can be used as an estimate of microbial exposure, rather than counting culturable or non-culturable intact microbes. Toxic (such as mycotoxins) or pro-inflammatory (such as endotoxins) components can be measured, but non-toxic molecules may also serve as markers of either large groups of microorganisms or a specific microbial genera or species. Some markers for measuring fungal biomass include ergosterol measured by gas chromatography-mass spectrophotometry (GC-MS) (Miller and Young 1997) or fungal extracellular polysaccharide measured with specific enzyme assays (Douwes *et al.* 1999), which allows partial identification of the mould genera present. Volatile organic compounds produced by fungi may be suitable markers for fungal growth (Dillon *et al.* 1996).

Toxicity markers such as endotoxin, a component of the cell wall of Gram-negative bacteria, and, less frequently, β -(1-3)-glucans, a cell wall component of fungi, are measured when analysing bioaerosols, due to their ability to cause lung tissue inflammation. The presence of β -(1-3)-glucans can be detected by either enzyme immunoassay or an assay based on the *Limulus* amoebocyte lysate (LAL) test, which is prepared from blood cells of the horse shoe crab *Limulus polyphemus* (Levin and Bang 1964). Animal studies have suggested that β -(1-3)-glucans may act synergistically with endotoxin to cause airway inflammation, but the results have not been verified (Fogelmark *et al.* 1992, 1994, 2001).

There have been no reports of the presence of β -(1-3)-glucans by researchers examining bioaerosols in swine or poultry confinement buildings. Much more attention has been paid to endotoxin levels, which can cause lung obstruction even at low levels of exposure. Livestock buildings have presented some of the highest endotoxin concentrations seen anywhere. The concentration of endotoxin is best sampled using liquid impingers or air sampling filters (Duchaine *et al.* 2001).

As already described above, Zucker *et al.* (2000) found a good correlation between the use of impingers and filtration for examining endotoxin in animal houses. Thorne *et al.* (1997) examined the effect of filter material on the sampling of endotoxin in swine and poultry buildings and found that polycarbonate filters led to lower concentrations of endotoxin than glass fibre filters. Traditionally, endotoxin concentrations have been determined by conducting the LAL test (Thorne *et al.* 1997, Douwes *et al.* 1995) with

either impinger liquid or following extraction from filters. Levin and Bang first described the use of LAL from the blood of the horseshoe crab to detect bacterial endotoxins in 1964. The original test depended upon the detection of a gel produced as a result of clotting (Levin and Bang 1964). Other LAL-based endotoxin assays that have subsequently been developed include endpoint detection of turbidity, enzymatic release of a chromophore from a chromogenic substrate and, more recently, kinetic turbidimetric and chromogenic assays (Wachtel and Tsuji 1977; Levin 1979; Harada *et al.* 1979; Ditter *et al.* 1982; and Milton *et al.* 1992).

Two research groups have examined different *Limulus*-based tests for the analysis of endotoxin in swine and poultry buildings. Reynolds and Milton (1993) initially compared an endpoint chromogenic LAL test and a kinetic *Limulus* assay with resistant parallel line estimation (KLARE). They found significant differences between the methods when sampling dust from one particular poultry house, but the results were comparable when sampling from other poultry houses. Reynolds and Milton (1993) suggested that possible sources of disagreement between the LAL tests may include: changes to the filters used to collect dust during transit; different extraction procedures (sonication in buffer for one hour versus rocking in water for two hours); sample diluent; lysate preparation (turbidimetric versus chromogenic); response (kinetic versus endpoint); and data analysis. In 1997, Thorne *et al.* also compared an endpoint chromogenic-based LAL test and KLARE for two types of filter: polycarbonate and glass fibre. In addition, these researchers examined two aqueous extraction methods (vigorous shaking versus gentle rocking). They found that the extraction method had little effect on the measured endotoxin concentration, but that the use of glass fibre filters inhibited the KLARE assay. Further studies by Reynolds *et al.* (2002) compared inter-laboratory differences when endpoint and kinetic LAL-based assays were used to determine endotoxin concentrations from filters used to sample poultry houses, swine buildings and corn processing facilities. Statistical differences between the laboratories' results were apparent and Reynolds *et al.* (2002) suggested a need to standardise methods.

3.4 Novel detection methods for bioaerosol analysis

A variety of novel detection methods have been developed and used for the analysis of bioaerosols in recent years. In 1997, Lange *et al.* reported the application of flow cytometry and fluorescent *in situ* hybridisation (FISH) to the assessment of bioaerosols within swine confinement buildings. Bacteria collected with impingers or filters can be counted using FISH or flow cytometry after they are stained with a fluorochrome such as 4',6-diamino-2-phenylindole (DAPI). FISH involves the use of fluorochrome-labelled nucleic acid probes to target species-specific rRNA within morphologically intact cells (Lange *et al.* 1997).

The researchers found that their results supported the use of flow cytometry for the quantification of bioaerosols in agricultural environments. The general advantages of cytometry include its ability to enumerate microorganisms regardless of viability and to discriminate bioaerosols from inorganic debris by multi-parameter analysis, which could be standardised among laboratories. In addition, cytometry can be automated, which helps to reduce operator tedium. However, Lange *et al.* (1997) admitted that a general drawback of flow cytometry is the initial high cost of a flow cytometer. Other disadvantages include laborious and complicated procedures, high costs per sample, unknown validity and the inability to detect possibly relevant toxic or allergenic components of cell debris. In addition, the potential for identifying microorganisms is limited for most of these techniques, although FISH proved to be sensitive enough to identify Gram-negative bacteria in air from the swine building. However, Lange *et al.* (1997) suggested that further work is needed on both techniques.

In 2001, Szponar and Larsson reported using GC-MS to characterise microbial communities in bioaerosol samples from a domestic house and a swine building. This technique utilised chemical markers for endotoxin (3-hydroxy fatty acids), fungal markers (ergosterol) and marker of bacterial biomass (muramic acid). A disadvantage of this method is that the dust samples had to be hydrolysed and subjected to various chemical manipulations in order to render the markers suitable for analysis. This is a time consuming process. However, the researchers did find significant differences in measured concentrations of endotoxin, fungi and bacteria between the two sampling sites. They believe that GC-MS can accurately determine markers, even when present at trace levels in chemically complex matrices, and should be useful for evaluating the role of microorganisms in occupational settings.

Other novel detection methods that have been used to analyse bioaerosols in settings other than swine and poultry buildings include real-time PCR, denaturing gradient gel electrophoresis (for the evaluation of composting sites; Ishii *et al.*, 2000) and oligonucleotide microarrays. Indeed, oligonucleotide microarrays offer a fast, high-throughput alternative for the parallel detection of microbes in virtually any sample (Bodrossy and Sessitsch 2004).

3.5 Summary of detection methods

Bioaerosol sampling methods have evolved from solely culture-based collection and analysis to a wide range of analytical techniques. These may still involve culturing, but can also include chemical analysis of microbial components, endotoxin analysis and molecular-based detection. It may also be relevant to measure dust levels by gravimetric analysis. Combining all of these analyses with a single sampling method could prove beneficial, but will not be possible with some methods.

In Table 3.1 summarises the principal bioaerosol sampling methods, together with an assessment as to whether they would be compatible with this wide range of analytical techniques.

Table 3.1 Bioaerosol sampling methods

Detection method	Principle	Analyses with which compatible	Analyses with which <u>not</u> compatible	Cost vs. usefulness
Andersen impactor	Samples directly onto agar plates – single or multiple stages.	Culturable microorganisms only. Because of direct agar plate inoculation, it minimises losses due to handling.	Dust and particulate analyses; non-culturable microbial cell/cell wall constituents.	Costly equipment, fixed point sampling only; compatible with limited number of analyses and can only be run for short periods in highly contaminated environments. Need for repeated sampling runs, one for each agar media tested.
Other impactors	Samples directly onto agar plates or strips – single stage.	Culturable microorganisms only. Because of direct agar plate or strip inoculation, it minimises losses due to handling.	Dust and particulate analyses; non-culturable microbial cell/cell wall constituents or allergens.	Less costly equipment, usually with integral vacuum pump; fixed point sampling or hand-held devices; compatible with a limited number of analyses and can only be run for short periods in highly contaminated

Detection method	Principle	Analyses with which compatible	Analyses with which not compatible	Cost vs. usefulness
				environments, with smaller area agar strips. Need for repeated sampling runs, one for each agar media tested.
Liquid impingers	Collects by passing airstream through liquid	Culturable microorganisms, total cell numbers by filtering and fluorescent staining; liquid can be used to test for non-culturable microbial cell/cell wall constituents, DNA-based or allergen analysis.	Dust and particulate analyses by gravimetric analysis.	Low cost samplers and mid-cost sampling pumps; mostly fixed point sampling; low flow rate samplers compatible with personal breathing zone sampling. Can be run for extended periods but may experience loss of liquid through evaporation. Their glass construction means they are easy to clean and their contents can be seen, but liable to break. Potential changes in live/culturable microbial component during post-sampling storage and transportation.
High volume cyclone samplers	Collects by centrifugal impaction onto inner wall of sampler; deposit usually washed off and collected in liquid.	Culturable microorganisms, total cell numbers by filtering and fluorescent staining; liquid can be used to test for non-culturable microbial cell/cell wall constituents, DNA-based or allergen analysis.	Dust and particulate analyses by gravimetric analysis.	Low to mid-cost samplers and mid-cost sampling pumps; some versions with an integral pump. Fixed point sampling. Can be run for extended periods but may experience loss of liquid through evaporation. Their glass construction means they are easy to clean and their contents can be seen, but liable to break. Potential changes in live/culturable microbial component during post-sampling storage and transportation.
Personal cyclone dust samplers	Separates larger (inhalable thoracic) particles from smaller (respirable) particles and	Re-suspend deposit from filter into liquid. Culturable microorganisms, total cell numbers by fluorescent staining; liquid can be used to test for non-	None	Low cost samplers and mid-cost sampling pumps. Fixed point sampling for limited applications, mainly indoors; main use for personal sampling in breathing zone. Robust

Detection method	Principle	Analyses with which compatible	Analyses with which not compatible	Cost vs. usefulness
	collects latter onto filter; means of collecting respirable size fraction only. Traps airborne particles onto filter – battery operated pump and designed for wearing in a person’s breathing zone.	culturable microbial cell/cell wall constituents, DNA-based or allergen analysis. Dust and particulate analyses by gravimetric analysis (pre- and post-weighing of filters).		and simple sampling method and can be run for extended periods. Simple post-sampling storage and transportation. Dehydration stresses in sampling and post-sampling storage could cause changes in live/culturable microbial component. Standard method for respirable dust monitoring in work environments.
Personal filtration sampler, such as IOM samplers	Traps airborne particles onto filter – battery operated pump and designed for wearing in a person’s breathing zone.	Re-suspend deposit from filter into liquid. Culturable microorganisms, total cell numbers by fluorescent staining; liquid can be used to test for non-culturable microbial cell/cell wall constituents, DNA-based or allergen analysis. Dust and particulate analyses by gravimetric analysis (pre- and post-weighing of filters).	None	Low cost samplers and mid-cost sampling pumps. Fixed point sampling for limited applications, mainly indoors; main use for personal sampling in breathing zone. Robust and simple sampling method and can be run for extended periods. Simple post-sampling storage and transportation. Dehydration stresses in sampling and post-sampling storage could cause changes in live/culturable microbial component. Standard method for total inhalable dust monitoring in work environments.
High volume filtration, such as Partisol samplers	Traps airborne particles onto filter. Large, stand alone.	Re-suspend deposit from filter into liquid. Culturable microorganisms, total cell numbers by fluorescent staining; liquid can be used to test for non-culturable microbial cell/cell wall constituents, DNA-based or allergen analysis. Dust	None	Costly equipment usually with integral sampling pumps (bulky and heavy). Fixed point sampling. Can be fitted with automated sample filter changer. Robust and simple sampling method and can be run for extended periods. Simple post-sampling storage and transportation. Dehydration stresses in

Detection method	Principle	Analyses with which compatible	Analyses with which <u>not</u> compatible	Cost vs. usefulness
		analyses by gravimetric analysis (pre- and post-weighing of filters).		sampling and post-sampling storage could cause changes in live/culturable microbial component. Standard method for environmental dust monitoring (PM ₁₀ , PM _{2.5}).

3.5.1 Outdoor sampling and the detection of bioaerosols emitted from intensive farming confinement buildings

With the exception of personal samplers such as the IOM, which are designed to monitor the breathing zone of workers, the air sampling methods described in Sections 3.2 and 3.3 can be used to determine both outdoor and indoor bioaerosol concentrations (methods are summarised in Table 3.1). However, there are more factors to consider when sampling outdoor air, including the influence of wind direction and obstacles in the path of the bioaerosol such as trees and buildings and the distance from the bioaerosol source to the sampler. The volume of air to be sampled must also be considered. Impactors such as Andersen samplers can only be used for very short periods, as the plates quickly overload with microorganisms. Following incubation of the plates, it is not possible to calculate the bioaerosol concentrations as there are too many colonies on the plate to count accurately. High volume cyclone samplers or filtration samplers are better designed for outdoor use due to the large volumes of air that they can sample. These devices can operate for much greater periods of time, allowing for greater accuracy in determining bioaerosol concentrations and their microbial content.

4 Effect of growth stage, livestock activity and density on bioaerosol emissions

4.1 Growth stage effects & building type

4.1.1 Stages in swine growth

Pigs are managed in different types of confinement buildings depending on their growth stage. These stages of growth can be categorised as (Olsen and Bark 1996):

- lactating sow and offspring
- pre-nursery (10–30lb)
- weaners (30–75lb)
- fatteners (75–150lb) and
- finishing (150lb to market weight).

Accordingly, five types of buildings can be involved in swine production (Chang *et al.* 2001b):

- breeding (for pre-pregnant and pregnant sows)
- farrowing (for delivered swine and newborn piglets)
- nursery (for weaned piglets less than 75lb)
- growing or fattening (for swine under approximately 150lb) and
- finishing (for swine awaiting slaughter)

In Europe, there are generally two distinct types of swine confinement buildings. The first type consists of nursery and farrowing buildings. These buildings hold a high number of pigs in small pens and the animals are more active and easily disturbed. The second type of building is known as a fattening or finishing building; the pigs are kept here until they are approximately 90–100kg when they are taken away to be slaughtered (Attwood *et al.* 1987). Concentrations of dust, microbes and endotoxin recorded by a variety of research groups are summarised in Appendix 2, according to the stage of pig growth.

Comparisons of dust and endotoxin levels between nursery and farrowing buildings and finishing buildings by Attwood *et al.* (1987) showed that the nursery and farrowing buildings have substantially higher dust levels than the fattening buildings. In contrast, Donham *et al.* (1986) found the total dust to be much higher in the finishing building and nursery building than in the farrowing buildings. However, both research groups found that the two major constituents of the aerosols are grain particles and dried faecal matter. The grain particles were larger than the faecal particles and proportionally more abundant in the finishing buildings. This meant that the respirable fraction of dust was much greater in nursery and farrowing buildings than in finishing

buildings. Dutkiewicz *et al.* (1993) found similar levels of total dust in both farrowing units and fattening sheds. Chang *et al.* (2001a) found that, whilst studying open style swine houses in Taiwan, the nursery stalls were contaminated with significantly higher levels of endotoxin and dust when compared to farrowing and fattening stalls.

Attwood *et al.* (1987) and Chang *et al.* (2001a) agreed that the nursery stalls contained the highest airborne concentrations of total dust and endotoxin, as measured by static air samplers. However, Chang *et al.* (2001a) also reported that workers wearing personal samplers in the nursery stalls were not exposed to the highest levels of either respirable dust or respirable endotoxin. Instead, this was found for those working in the finishing stalls. Chang *et al.* (2001a) suggested that this inconsistency might be due to variations in the respirable portion of total endotoxin and dust among the different types of stall. Mechanical ventilation was much reduced in the finishing stalls and the flooring was not slatted, as was the case in the other pens. Cleaning was on a monthly basis, compared with a daily basis in the nursery stalls. Variations in the time periods spent in the different stalls by the workers may also have a bearing on these results. It was observed that the finishing stalls were much larger than the other stalls and that the workers spent longer periods in these stalls attending to the pigs.

Donham (1991) reported that farrowing barns had substantially higher (50–150 per cent) amounts of airborne microbes than finishing buildings. Curtis *et al.* (1975) reported the bacterial concentrations to be higher in fattening buildings than in nursery units. These results cannot be considered as representative, however, as the fattening units were sampled during cold weather, while the farrowing units were sampled in summer. Fiser (1970) and Dutkiewicz *et al.* (1993) found similar concentrations of microbial contamination in fattening and farrowing houses. Cormier *et al.* (1990) found some differences when comparing the same type of units, but reported that their data were not clear cut and that these differences were only observed for total bacteria.

A further study by Chang *et al.* (2001b) quantified the levels of airborne microorganisms in breeding, fattening and finishing stalls, which were primarily open-air buildings, as well as in partially enclosed farrowing and nursery stalls. They found the highest airborne levels of culturable bacteria and Gram-negative bacteria in the finishing units. Gram-negative bacterial concentrations in the air of the breeding, farrowing and nursery stalls were ten-fold lower than the mean level in the finishing swine building. The air in the nursery stalls was also least contaminated with culturable and Gram-negative bacteria. There was no significant difference in the airborne fungi concentrations between the varying types of pig stall, with *Cladosporium* representing more than 90 per cent of the identified fungi in all five types of stall. The researchers suggested that the relatively high concentrations of airborne culturable Gram-negative bacteria identified in the air of the finishing stalls were probably due to the high pig density and infrequent cleaning (Chang *et al.* 2001b). The fact that at least half of all types of swine buildings tested by Chang *et al.* (2001b) had natural ventilation, with the exception of the finishing units, also helps to explain why the finishing units had the highest bacterial concentrations.

4.1.2 Stages in poultry growth

Poultry are kept in confinement buildings for a variety of purposes. Modern methods for the mass production of chicken eggs require advanced layer management systems, which consist of banks of cages densely stocked with egg-laying hens. Commercial egg layers commence egg production at 16–22 weeks of age and can have produced 250–300 eggs by 70 weeks of age (Glatz *et al.* 1996). Broiler and turkey production essentially involves rearing and fattening the birds in pens prior to slaughter. Chickens grow quickly and reach market weight of 2.2kg within 42 days. Once ready for market,

each bird must be caught and shackled prior to slaughter. Feathers are then plucked and the meat is processed.

The literature relating to the quantity and composition of bioaerosols in hatcheries is very limited. Larsson *et al.* (1999) compared the health effects on workers using both a cage rearing system and a cage-less rearing system for laying hens. The cage-less system consisted of free loose-laying hens in pens of bedding. This method increased the exposure time for the workers in the poultry houses, as a result of having to collect eggs by hand over all areas of the floor. Martensson (1995) also suggested that dust levels would be higher in cage-less systems due to increased activity of the hens. This was confirmed by Larsson *et al.* (1999), who found that the inhalable dust concentrations were significantly higher in facilities without cages. Total dust levels were nearly twice as high in the cage-less systems. Venter *et al.* (2004) examined bioaerosols in a typical automated chicken egg layer management system, with and without a controlled internal environment. The main difference between the hatcheries was the waste management system, with the controlled environment having a conveyor belt system that removed faecal matter on a daily basis compared with the faecal matter dropping into a pit that was emptied bimonthly. Despite the more rapid removal of faeces by the conveyor belt, the daily scraping of the belt created a bioaerosol that subsequently contaminated the eggs.

There are considerably more studies of bioaerosols in livestock houses used for broiler production, but, even so, much less is known about bioaerosols associated with poultry production compared to swine production. Saleh *et al.* (2005) is one of the few teams of researchers to study the influence of the age of the broiler on the microbial content of bioaerosols in confinement buildings. They examined bioaerosols on a weekly basis during the five weeks that chickens are contained in confinement buildings to fatten them up. The results of this investigation showed that high concentrations of inhalable and respirable dust, microorganisms and endotoxins were present in the air. The concentrations of all the pollutants increased with the age and weight of the birds, with the highest amounts reached in the fourth week of fattening. A slight reduction was noticed in the final week and this was probably due to the high stock density in the last days of the fattening period, which reduced the activity of the birds. A reduction in animal activity has previously been linked to a lower microbial content of bioaerosols (Chang *et al.* 2001a).

These results are similar to those of Vucemilo *et al.* (2005), who presented their findings at the same conference as Saleh *et al.* (2005). These authors found that the quantities of both bacteria and fungi increased between the first and fifth week of fattening: 3×10^6 cf 5.4×10^6 and 9.8×10^4 cf 3×10^5 , respectively. They also reported that, after one week of fattening, the dominant species of bacteria was *Serratia sp.* and the dominant species of fungi were *Mucor sp.* and yeasts. However, after five weeks of fattening, the bacterium *E. coli* had become more dominant and only yeasts were detected. This suggests a link between the stage of fattening and the microbial content of associated bioaerosols. Recorded concentrations of dust, microbes and endotoxin isolated from hatcheries and broiler houses are summarised in Appendix 2.

The final stage of poultry production occurs in a broiler processing plant. Kotula and Kinner (1964) were the first workers to examine airborne microorganisms in broiler processing plants. The factories that were examined each consisted of four processing rooms, where the activities of shackling, dressing, eviscerating and holding took place. The greatest numbers of bacteria were found in the shackling and dressing rooms, which is where the greatest bird activity occurred. Zottola *et al.* (1970) found large numbers of bacteria, including *Salmonella sp.*, in the air of the shackling areas in turkey processing plants. The presence of *Salmonella* is likely to be due to the presence of faeces; it was detected only infrequently elsewhere in the processing plant. Patterson (1973) found that the highest concentrations of bioaerosols were also in the areas

associated with live birds and showed the benefits of segregating the areas associated with shackling and dressing from other parts of the processing plant. However, Patterson recorded raised levels of *Staphylococcus aureus* not of human origin in each room of one of the plants. This was reportedly due to the fowl being heavily contaminated prior to processing. More recent studies (Lenhart *et al.* 1982; Lutgring *et al.* 1997; Whyte *et al.* 2001) have found little new evidence. All the research groups agreed with past reports that the highest concentrations of bacteria are associated with the shackling and plucking of birds and that these areas must be kept separate from other areas of the processing plant. Lenhart *et al.* (1982) isolated large numbers of Gram-negative bacteria from the workers' breathing zones. Whyte *et al.* (2001) examined the concentrations of airborne mesophilic bacteria within poultry processing plants and found large numbers of *E.coli*, *Enterobacteria* and *Campylobacter* in the shackling and plucking areas, associated with the faeces of live birds. This was also suggested as the source of Gram-negative bacteria by Lenhart *et al.* (1982). None of these species were isolated from other areas of the plants.

4.1.3 Comparison of bioaerosols in and from swine buildings and poultry houses – effect of growth stage/type of building

There are very few studies that have compared the dust or microbial content of bioaerosols detected within poultry houses with those detected within swine confinement buildings. It is difficult to make comparisons between bioaerosols in swine buildings and poultry houses due to variations in many factors, such as the sampling method, geographical location and type of building. It is also difficult to compare emissions of bioaerosols from pig and poultry buildings to the wider environment due to the many variables such as meteorological conditions, sampling locations, sampling frequency etc. This is discussed in further detail in section 8.

Dust concentrations

Clark *et al.* (1983) found concentrations of total dust to be higher in swine buildings than in poultry houses (3.08 mg/m³ *cf.* 2.34 mg/m³). Hinz and Krause (1987) reported similar results for total dust when comparing swine buildings and poultry houses (3.8 mg/m³ *cf.* 2.4mg/m³) and found a greater proportion of respirable dust in swine buildings (12 per cent *cf.* 9 per cent). However, both studies compared swine buildings containing pigs of an undisclosed age to poultry houses containing caged laying hens. The activity of caged hens is restricted compared to that of broiler hens or layer hens kept on perches in open pens. In contrast, Takai *et al.* (1998) found that inhalable and respirable dust concentrations were much greater in poultry houses than swine buildings. They also collated bioaerosol data from swine buildings containing sows, weaners and fatteners and compared the overall mean values with collated data from poultry houses containing caged layers, layers on perches and broiler hens. They reported that the overall mean inhalable and respirable dust concentrations were 3.60mg/m³ and 0.45mg/m³ for poultry and 2.19mg/m³ and 0.23mg/m³ in swine buildings, respectively.

Microbial concentrations

Concentrations of airborne microorganisms within swine and poultry confinement buildings vary greatly in the literature. This is due to variations in the type of building, geographical location, type of ventilation and sampling method. Very few authors have compared bioaerosols in poultry houses with those in swine confinement buildings.

Seedorf *et al.* (1998a) showed that the highest mean concentrations of airborne bacteria were found in confinement buildings that housed broilers, whereas laying hens and pigs had similar concentrations ($6.43 \log \text{ cfu/m}^3$ *cf* $5 \log \text{ cfu/m}^3$). There was little difference in the total bacterial concentrations between buildings housing sows, weaners and fattening pigs. In contrast, concentrations of Gram-negative Enterobacteriaceae were much higher in swine buildings and poultry houses containing layer hens than in broiler houses. Enterobacteriaceae concentrations were slightly higher in buildings containing fattening pigs and weaners than in those containing sows. Bakutis *et al.* (2004) found the highest microbial contamination in poultry houses, where both the average amounts of microbes and the corresponding amount of Gram-negative bacteria were 2.5 and 1.3 times higher than in swine buildings, respectively.

Seedorf *et al.* (1998a) found that fungal concentrations were slightly higher for poultry houses overall compared to swine buildings ($4.0 \log \text{ cfu/m}^3$ *cf.* $3.7 \log \text{ cfu/m}^3$). During the daytime, bioaerosols in broiler houses contained higher concentrations of fungal particles than buildings housing pigs and laying hens, but contained similar concentrations to buildings housing sows during the night time. In contrast to levels of Enterobacteriaceae, there were greater concentrations of fungi in buildings housing sows than in those housing weaners or fattening pigs. Houses of laying hens contained lower levels of fungi than swine confinement buildings. However, Seedorf *et al.* (1998a) did not record whether the laying hens were kept on perches or in cages.

Endotoxin concentrations

Clark *et al.* (1983) compared the endotoxin content of airborne dust in swine buildings with that found in poultry houses containing caged hens. Concentrations of airborne endotoxins were much higher in the poultry houses than the swine confinement buildings ($0.31 \mu\text{g/m}^3$ *cf.* $0.12 \mu\text{g/m}^3$). Seedorf *et al.* (1998a) measured concentrations of airborne endotoxins in 241 swine buildings, cattle barns and poultry houses in four European countries. Compared with swine buildings and poultry houses, they found that the endotoxin concentrations were consistently lower in cattle barns. However, there was great variation in the concentrations of endotoxins detected in similar style buildings in different European countries. Analysis of the mean data according to animal type by Seedorf *et al.* (1998a) showed that poultry houses of layer hens contained the greatest concentrations of endotoxin in the daytime, yet those containing broiler hens contained the greatest concentrations at night. Swine buildings containing weaner pigs had higher endotoxin concentrations than those containing fattening pigs, which were higher than those containing sows. This trend is not consistent with the data collected by the same authors for the concentrations of Gram-negative Enterobacteriaceae, which were found at much lower concentrations in broiler houses than in swine buildings or in poultry houses of layer hens. Overall, Seedorf *et al.* (1998a) found that mean values in poultry houses ranged from 339 ng/m^3 to 860 ng/m^3 air for inhalable dust and from 29.6 ng/m^3 to 72 ng/m^3 air for respirable dust. This compared to inhalable endotoxin concentrations ranging between 52.3 ng/m^3 and 186 ng/m^3 and respirable endotoxin concentrations ranging between 7.4 ng/m^3 and 18.9 ng/m^3 air in swine buildings. Bakutis *et al.* (2004) also reported that endotoxin contamination in the air of poultry houses was more than three times higher than in the air of swine buildings.

4.2 Effect of animal activity

Both Chang *et al.* (2001a) and Attwood *et al.* (1987) suggested that the increased concentrations of dust and endotoxin in nursery buildings compared to fattening units were due to the greater activity of young swine and the high pig density. Attwood *et al.*

(1987) also cited the reduced ventilation in the nursery and farrowing building, which was designed to conserve heat, as a factor that could lead to increased levels of dust and endotoxin.

However, Chang *et al.* (2001a) found similar temperature and wind velocities in all of the investigated stalls, which they attributed to the open style of swine buildings in Taiwan. They reported that farrowing stalls contained the second highest levels of both endotoxin and total dust. Growing pigs held in the farrowing stalls were not as active as young piglets held in the nursery stalls, but the farrowing stalls were still densely stocked. High endotoxin concentrations were also found in the finishing buildings, where adult pigs were crowded into pens that were significantly contaminated with Gram-negative bacteria (Chang *et al.* 2001a). Chang *et al.* (2001a) suggested that reducing the pigs' density and activity would lead to lower levels of Gram-negative bacteria and endotoxins in the stalls. These researchers cite a further study (Chang *et al.* 2001b) showing that breeding buildings containing a low density of inactive pregnant pigs and cleaned on a daily basis had relatively low concentrations of airborne Gram-negative bacteria and the lowest levels of both endotoxins and dust (Chang *et al.* 2001b). The data collected by Chang *et al.* (2001a,b) are summarised in Appendix 2.

Several previous investigations (Curtis *et al.* 1975; Nilsson 1982; Gustafsson 1994; Pedersen 1993; van't Klooster *et al.* 1993) have shown that the activity of swine has a strong influence on the concentration of dust in the air. The dust concentration normally increases during periods of high activity, such as when the pigs are weighed and fed. Curtis *et al.* (1975) reported a five-fold difference in the number of bacteria per m³ of air between a finishing house where 80 per cent of the pigs in a pen were lying dormant and a house where just 10 per cent of the pigs were dormant. This finding is corroborated by the fact that several researchers (Curtis *et al.* 1975; Gustafsson 1994, 1999; Takai *et al.* 1998; Seedorf and Hartung 2000) have reported sampling higher concentrations of dust and microorganisms in the day than at night.

As already described, the process of shackling live birds prior to slaughter leads to significantly higher concentrations of airborne dust and microbes, as a result of the birds flapping their wings (Kotula and Kinner 1964; Lenhart *et al.* 1982; Lutgring *et al.* 1997; Whyte *et al.* 2001). Carlson and Whenham (1968) conducted the only study to compare the activity of poultry and swine on the rate of increase in microbial contamination of the air. These researchers emptied and cleaned a broiler house and farrowing unit and then monitored the air following the introduction of broilers and piglets. They found that airborne bacterial concentrations increased at a faster rate in the broiler house.

In 1964, Magwood reported that microbial counts in the air of poultry hatcheries were several times higher during periods of maximum activity than at times of minimum activity. Martenson *et al.* (1995) and Larsson *et al.* (1999) reported that airborne contamination was much greater in units containing cage-less layer hens than in units containing caged birds. Takai *et al.* (1998) compared airborne dust concentrations in units containing caged layer hens, those on perches (cage-less) and broiler chickens. They found that the mean inhalable and respirable dust concentrations in the units containing caged layer hens were much lower than in the percheries. Similar findings were made by Martenson *et al.* (1995) and Larsson *et al.* (1999), who reported that, when compared to the dust concentrations in the broiler houses, the layer hens produced significantly less dust. This is consistent with a similar study performed by Seedorf and Hartung (2000), who found significantly greater airborne bacterial concentrations in broiler houses than in houses containing layer hens. Takai *et al.* (1998) noted that in percheries and buildings for caged layers there were clear differences in inhalable dust concentrations between day and night, as had been previously reported for swine. However, this is not the case for broiler houses.

Bioaerosol concentration data reported by Takai *et al.* (1998) for poultry houses is summarised in Appendix 3 according to the type of poultry and housing.

Seedorf and Hartung (2000) also noted little difference in the average airborne bacterial concentrations during the day and at night in broiler houses. The mean concentration of dust generated continuously by the broilers was virtually identical to that produced by layer hens in percherries during the day, when they are free to roam. This continuous activity by broilers may be a reason why airborne concentrations in broiler houses has been reported to be significantly higher than in layer units and swine buildings (Seedorf and Hartung 2000).

4.3 Effect of stock density

There is little reported information on the effect of livestock density on airborne concentrations of dust and microorganisms. In 1997, Banhazi and Cargill suggested that airborne bacterial levels could be controlled by reducing the stocking rate of swine. In the same year, Gustafsson stated that the most important factors determining dust levels are the activity of the animals and the stocking density. Gustafsson (1999) investigated the influence of the number of pigs on the production of dust by changing the number of animals in a unit when their average body weight was in the range of 86–98kg. The results showed that the amount of dust generated is proportional to the number of animals. This study also showed that the amount of dust increased with the body weight of the pigs.

Chang *et al.* (2001a) suggested that higher concentrations of dust in nursery and farrowing stalls compared to breeding stalls may be due to the higher density of animals. They therefore proposed that reducing livestock density could lead to reductions in airborne contamination. During a survey of ventilation systems, Seedorf *et al.* (1998b) suggested that certain farmers may have increased livestock density to the point where the ventilation system is unable to cope with the demand for air exchange. Increasing livestock density could therefore be a false economy if the health of the animals and the workforce suffers due to poor air quality and increased levels of dust and microbial contamination.

4.4 Summary – growth stages, animal activity & stock density

The growth stage of the animal has an effect on bioaerosol emissions in terms of the way the animals are managed.

For pigs, nursery and farrowing buildings tend to hold a lot of animals that are more active and easily disturbed when compared to fattening and finishing buildings. The effect on bioaerosol concentration, however, is not always clear:

- Nursery & farrowing buildings generally have substantially higher dust levels when compared to finishing buildings. However another researcher found that dust levels were higher in finishing and nursery buildings when compared to farrowing buildings
- The major constituents of the dust from pig buildings of all types are grain particles and dried faecal matter. Grain particles were bigger than faecal particles and more abundant in finishing buildings

- Respirable dust concentrations are higher in nursery and farrowing buildings than finishing buildings (more abundant smaller particles in nursery/farrowing buildings)
- Nursery buildings have the highest airbourne total dust and endotoxin concentrations as opposed to farrowing and finishing buildings but confusingly worker exposure showed highest respirable dust and endotoxin exposure in the finishing buildings. This was possibly due to differences in respirable portions of total dust and endotoxins, variations in how the buildings were cleaned and ventilated and the amount of time workers spent in each type of building. For example finishing pens were much bigger and are cleaned once a month instead of daily as in the nursery pens. In addition, workers in these pens tend to spend much longer within them than in the nursery pens.
- Frequency of cleaning combined with high stock density and mechanical ventilation can have a large impact on microbial concentration e.g. one study found the highest levels of bacteria in the finishing building where stock density was high, ventilation mechanical and cleaning less frequent than in other types of building

For poultry, birds are either kept for egg laying (in cages or not) or raised as quickly as possible for meat (broilers)

Laying hens:

- Inhalable dust concentrations are significantly higher in buildings without cages
- The waste management system used can affect bioaerosol emissions – conveyor belt system where faecal matter is removed daily or faecal matter being collected in a pit and emptied bimonthly – the conveyor belt system produces higher bioaerosol levels

Broilers:

- Broiler buildings have high concentrations of inhalable and respirable dust, microorganisms, and endotoxins. Moreover, concentrations increase with bird age and weight
- The type of bacteria and fungi making up the bioaerosol varies as the birds get older – after one week of fattening, *Serratia* sp were the dominant bacteria and *Mucor* sp and yeasts the dominant fungi. After five weeks *E.coli* was the dominant bacteria and only yeasts were found
- Broilers are also sometimes slaughtered and processed on site – this involves shackling live birds – high levels of bacteria are found at these stages including *Salmonella* sp. These areas should be segregated from other areas of the process

It is difficult to compare bioaerosol emissions from pig and poultry facilities (and sometimes the evidence seems contradictory) but there are differences around dust, microbial and endotoxin concentrations:

Dust concentrations:

- In one study total dust concentrations were higher in pig buildings than caged layer hen buildings, as were respirable dusts (but broiler hens are more active and the age of the pigs was unknown)

- Another study found higher concentrations of inhalable and respirable dusts in poultry as opposed to pig buildings. This study compared bioaerosol emissions from sows, weaners and fatteners with caged layers, layers on perches and broilers. Overall inhalable and respirable dust concentrations were higher for the poultry buildings with broilers being highest of all

Microbial concentrations:

- Concentrations reported in the literature vary widely for both pig and poultry buildings due to differences in buildings, geographical location, sampling method etc.
- Highest concentrations of total airbourne bacteria were found in broiler houses, with pigs and laying hens being similar, plus there was little difference between sows, weaners and fattening pigs in one study. For Gram-negative bacteria this was reversed with the highest concentrations in pig buildings, then laying hens and finally broiler houses
- Another study found the highest microbial concentrations in poultry buildings as opposed to pig buildings and this included the Gram-negative bacteria
- Fungal concentrations were slightly higher in poultry as opposed to pig buildings, with daytime concentrations in broiler houses being higher than laying hens or pigs but at night levels dropped to a similar level with buildings housing sows. Laying hens contained lower levels of fungi than pig buildings (but unclear whether they were caged or not)
- Sow buildings have higher fungal concentrations than weaners or fattening pigs

Endotoxin concentrations:

- Concentrations of airbourne endotoxins were much higher in caged laying hen buildings than pig buildings. Another study found that endotoxin concentrations were three times higher in poultry buildings when compared to pig buildings
- Endotoxin concentrations are lower in cattle barns when compared to pig or poultry buildings but there was great variation in the concentrations recorded
- Layer hen buildings have highest endotoxin concentrations during the day, broiler houses at night
- Weaner pig buildings had higher endotoxin concentrations than fattening pig buildings with sow buildings having the lowest – this is opposite to concentrations of Gram-negative bacteria found in the same study

Animal activity and stocking density also have effects on dust concentrations and bioaerosol emissions:

- Animal activity rates vary depending on the growth stage of the animal in pigs. Increased dust and endotoxin concentrations can be found in nursery buildings as opposed to fattening units possibly due to greater activity and higher stocking rates in the younger animals. This is not always the case and it is the type of building and how the pigs are kept (high stock density, levels of cleaning etc.) that is important

- Dust concentrations can also increase depending on what is happening to the pigs. For example dust concentration normally increases during weighing of the animals and during feeding. Similarly dust levels are higher during the day as opposed to the night (when many more animals are not moving around so much)
- For poultry, shackling prior to slaughter increases dust concentration due to the birds flapping their wings
- Microbial concentrations in poultry hatcheries are higher at times of maximum activity when compared to minimum activity
- Significantly greater airbourne bacterial concentrations are found in broiler houses when compared to laying hens
- Dust concentrations (inhalable and respirable) are higher for broilers when compared to laying hens in cages and on perches
- Little or no difference in airbourne bacterial concentration and inhalable dust concentration was found between day and night in broiler houses but this is not the case for laying hens (percheries and caged birds) (Appendix 2)
- Comparing pig and poultry buildings, airbourne bacterial concentrations increase fastest in a broiler house when starting from a clean empty building

The effects of stock density are related to animal activity:

- In pigs, the amount of dust produced in the building is proportional to the number of animals and increases with bodyweight
- High stock densities can also affect the ventilation system to the point where it is no longer effective
- Reducing livestock density could lead to a reduction in airbourne distribution of bioaerosols.

5 Effect of ventilation and housing conditions on bioaerosol emissions

5.1 Effect of ventilation – growth stage & associated building types

The structural design of confinement buildings can greatly influence the ventilation and, in turn, the air movement and air quality within the building. Ventilation is just one of the physical processes by which airborne microorganisms are cleared from the air within buildings. The other processes include sedimentation, impaction and electrostatic precipitation. The major purpose of a ventilation system is to provide an aerial environment that can help maintain animal and worker health, as well as to ensure satisfactory rates of productivity. The need for ventilation is governed by two requirements: the maximum ventilation rate is necessary to prevent hyperthermia, while the minimum ventilation rate is set to provide an acceptable thermal and aerial environment for animal welfare.

The performance of a ventilation system can be evaluated by its ability to control air temperature, relative humidity and air speed. It is also associated with the adequate removal of gases, dust and microorganisms. The rate of dilution of microbes is set by the local air change rate at the source of the microorganisms and this can be much less than the overall air change within the building as a whole (Wathes 1987). This is especially the case if the air is poorly mixed. The ventilation rate governs the emission of aerial pollutants from the building and the design of the ventilation system is a major factor in determining the environmental impact of a livestock building. In practice, ventilation rates normally range from two to 200 air changes per hour, but may exceed this maximum on occasions (Wathes 1987).

Seedorf *et al.* (1998b) have recommended values for the minimum (winter) and maximum (summer) ventilation rates for a variety of animal types (see Table 5.1). These recommended ventilation rates are defined on an animal basis and, for comparison purposes, have been extrapolated to 500kg live weight from data calculated by Hilliger (1990).

Table 5.1 Recommendation for ventilation rate (m³/500kg live weight)

Animal	Body weight (kg)	Minimum winter	Maximum summer
Sow	200	50	500
Weaner	20	100	1000
Fattening pig	100	50	500
Layer hen	2	175	2000
Broiler chicken	2.7	278	1853

Source: Seedorf *et al.* (1998b)

Seedorf *et al.* (1998b) also conducted a survey of ventilation rates in more than 300 livestock buildings across northern Europe. The researchers examined both mechanically- and naturally-ventilated buildings in summer and winter, but admitted that the testing of naturally-ventilated buildings led to inaccurate measurements. However, the survey showed that air temperature could be controlled by both mechanical systems and natural ventilation over a wide range of temperatures up to 17°C. Above this temperature, the building temperature became dependent upon the weather unless a cooling system was in place. This suggests that the capacity of the ventilation systems may have been too low and the researchers did report maximum ventilation rates below those recommended by Hilliger (1990). However, Seedorf *et al.* (1998b) also reported that there had been a tendency to raise stock density levels in many of the livestock buildings. This may have resulted in the ventilation systems no longer being capable of meeting demand. This tendency was particularly noted for sows and weaners housed on slats, caged layer hens and broiler chickens.

Gustafsson (1999) felt there was little consensus among researchers about the influence of ventilation on dust concentrations. He cited the work of Bundy and Hazen (1975) and Bundy (1984), which showed a decrease in the number of dust particles with increasing airflow rate, and that of Nilsson (1982) and his own past work (Gustafsson 1994), which suggested a less pronounced influence of ventilation rate on the total concentration of airborne dust. In 1999, Gustafsson reported that the ventilation rate had a limited effect on dust concentrations, based on a study of ventilation rates in insulated swine buildings. He examined a swine building with total climate control, including a high-speed re-circulating air inlet; a building with climate control and a breathing ceiling as an air inlet; and an uninsulated building with automated natural ventilation. The fraction of dust exhausted away from the insulated buildings was low (20–30 per cent), while increasing the ventilation rate only had a limited effect on dust concentration in the swine building with a high-speed re-circulating air inlet. Gustafsson (1999) reported that ventilation had its main diluting effect on particles larger than 1.0µm and that, for the examined ventilation system, the ventilation rate had no effect on particles smaller than 1.0µm (Figure 5.1). According to Gustafson, the reason for the very limited effect of ventilation on total airborne dust concentrations was that the settling of dust on different surfaces was a more important mechanism for removing dust particles from the air than the ventilation rate.

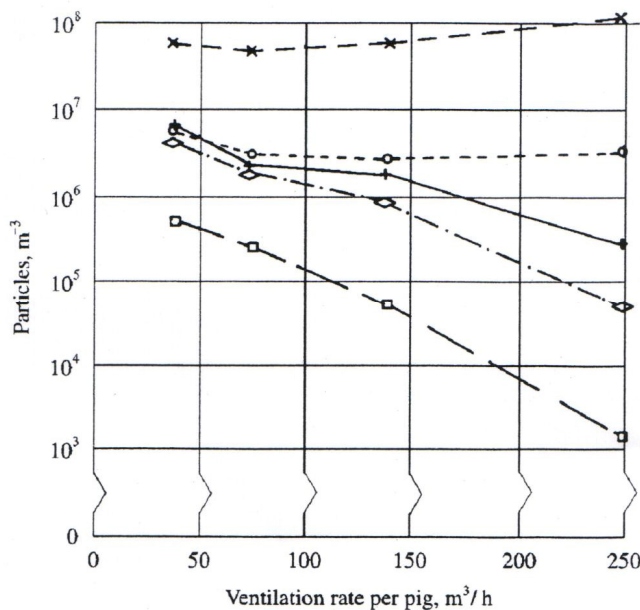


Figure 5.1 Influence of ventilation rate on the number of dust particles of different sizes

Notes: x—x = 0.3–0.5µm; o—o = 0.5-1.0µm; +--+ = 1.0–2.0µm; ◇--◇ = 2.0–5.0µm; □--□ = >5.0µm. Source: Gustafsson (1999).

Predicala *et al.* (2002) compared concentrations of total and respirable airborne microorganisms in naturally- and mechanically-ventilated finishing buildings. The buildings, which were located on the same farm, did not show any significant difference in concentrations.

5.1.1 Seasonal effects on the ventilation of confinement buildings

The majority of confinement buildings examined in the peer reviewed literature were enclosed and relied on mechanical control of a ventilation system. However, some did have windows and shutter doors that were opened in summer months to bring in some fresh air. Chang *et al.* (2001a,b) were the only researchers to study open air swine houses. These are used in subtropical countries, such as Taiwan, due to the relatively high ambient temperatures. Plastic curtains that can be rolled down in winter are used instead of fixed constructions. Chang *et al.* found, overall, that the microbial concentrations in open air swine houses were significantly lower than those reported by groups studying enclosed confinement buildings in the US and Europe. Curtis *et al.* (1990) compared enclosed swine buildings with a building that had been modified to be open-fronted. Their findings were in agreement with those of Chang *et al.* (2001a,b), in that airborne dust levels were generally lower in buildings open to the outside air.

Several research groups have reported reduced dust and microbial concentrations within confinement buildings in summer months compared to the same facility in the winter (Wilson 1987; Cormier *et al.* 1990; Thorne *et al.* 1992; Takai *et al.* 1998; Saleh *et al.* 2005; Zhao *et al.* 2005). Most of these researchers speculated that the higher concentrations in winter were due to reduced levels of ventilation, as windows and doors are closed to conserve heat. Boon and Carpenter (1987) suggested that, because pigs require a fairly high temperature for efficient food conversion (16–20°C), the temperature in swine houses is controlled by varying the ventilation rate and this control is at a minimum in cold weather. The result is a reduced dust clearance rate and high dust concentrations.

Curtis *et al.* (1975) demonstrated annual fluctuations of aerial dust and aerial microbial contamination within confinement buildings (the CFU/m³ was negatively correlated with the outside temperature). They also concluded that this phenomenon probably resulted from different ventilation rates during periods of cool and warm weather. However, Cormier *et al.* (1990) found that the level of airborne microbial contamination did not significantly vary as a function of outside temperature. These authors studied swine barns in the cold climate of Canada in a short period between January and April. It is unlikely that huge fluctuations in outside temperature were noted within this short period and a heating system was probably used to maintain the temperature in the barns, resulting in much poorer ventilation. This would also tie in with the fairly high microbial concentrations observed in this study.

Saleh *et al.* (2005) found similar summer and winter differences in concentrations of dust when examining broiler houses. The dust concentrations within the houses in summer were only half of those found in winter. These researchers noted that the temperature inside the broiler house varied only slightly between summer and winter, due to an automated ventilation and heating system, and suggested that the differences in dust concentrations were possibly due to the higher ventilation rate in summer. However, in none of the studies described above did the researchers corroborate their hypotheses that increased ventilation in summer led to reduced

internal dust concentrations by examining the dust concentrations being emitted from the swine buildings. Had they detected increased dust emissions in summer compared to winter, then the hypotheses would be correct.

5.2 Effect of housing conditions

5.2.1 Effect of feeding practices

In general, there are two different types of feed: wet and dry. Wet feed consists of foodstuff mixed with water, whey or beer yeast and dry feed comprises feed pellets, usually consisting of compressed wheat or fine grain types. In the case of dry feed, a separate water supply is also provided. Several research groups have examined the effect of feed type on dust concentrations within swine confinement buildings. Curtis *et al.* (1975) found that dry feed was a major contributor to dust levels in the air of swine buildings. Takai *et al.* (1986) and Attwood *et al.* (1987) compared the different feed types and found higher dust concentrations during dry feeding than wet feeding. However, Nilsson (1982) found that the type of feed (dry or wet) had limited influence on the daily averages of total dust concentrations in fattening and finishing swine buildings. Gustafsson (1997) agreed with these findings. Nilsson (1982) concluded that a considerable proportion of the dust originated from the pigs themselves. For both wet and dry feed, the dust concentrations increased during feeding times as a result of increased activity.

Wathes (1987) suggested that animal feed can act as a reservoir for fungi such as *Aspergillus flavus*, which produces aflatoxins, but he did not distinguish between wet or dry feed. Butera *et al.* (1991) showed that the genera of moulds identified in dry feed samples corresponded to those found in aerial dust within the swine building and were different to those isolated from the outside air. This suggests a direct link between feedstuff and bioaerosols in livestock buildings. Several studies (Gore *et al.* 1986; Gast and Bundy 1986; Chiba *et al.* 1987; Heber and Martin 1988; Takai and Pederson 1994) have shown that adding oil or fat to the feedstuff may decrease the amount of dust in swine buildings.

There are a number of feeding practices associated with intensive swine farming: floor fed versus trough feeding and either restricted or freely available. The specific feeding technique may have an indirect effect on the dust concentration, through its influence on the activity of pigs. Curtis and Drummond (1982) described animal feed as a powerful source of airborne dust, especially during distribution, and Robertson (1992) reported that significantly higher dust concentrations occurred during restrictive feeding compared to when the feed was freely available. This is in contrast to Gustafsson (1997), who suggested that having feed freely available tends to produce more dust than if it is restricted, due to the increased activity of the animals. Gustafsson (1997) also suggested that, for the same reason, there is more dust in the feeding passage during feeding in buildings with floor-fed pigs than in buildings with trough feeding. Unfortunately, no references to the feeding of poultry were found.

5.2.2 Effect of bedding

Traditionally, swine are housed without bedding on slatted floors over a pit or lagoon that collects faecal and other waste. This lagoon requires emptying on a regular basis. In the past decade, there has been a move towards on-site composting swine buildings, where pigs are raised on an enclosed compost bed consisting of peat or saw

dust. The animal density is smaller and the pigs are healthier than those housed on slatted floors (Rautiala *et al.* 2003). Furthermore, the workforce is less exposed to the gases produced by animal waste than when the traditional slatted floors are used (Louhelainen *et al.* 2001). However, the composting bed must be turned regularly to maintain proper aerobic and moisture conditions. Due to the potential exposure of the worker to high concentrations of microorganisms, this activity was investigated by Rautiala *et al.* (2003). They found that during the turning of compost, especially if it was made from peat, the concentration of airborne microorganisms was higher by a factor of 10–1000 compared to traditional slatted swine buildings (Rautiala *et al.* 2003). The concentrations of fungi and, in particular, thermophilic actinomycetes (the microorganisms most frequently responsible for Farmer's lung disease) were especially high in compost swine buildings (Rautiala *et al.* 2003).

Banhazi *et al.* (2005) compared concentrations of airborne bacteria and respirable endotoxins in swine buildings with and without deep-bedding. They found that greater concentrations were associated with the presence of bedding. The effect of manure cover on the pen floor was significant and there was a positive correlation between endotoxin concentrations and the internal humidity of the buildings. Banhazi *et al.* (2005) suggested treating the bedding to reduce dust levels, such as by incorporating vegetable oil or plant extract to reduce bacterial growth.

There are only a few reports on the effect of bedding on bioaerosols in poultry houses. Lovett *et al.* (1971) and Dennis and Gee (1973) identified the floor litter as the primary source of airborne fungi in a deep litter pullet house, with species changing according to pH value, moisture content and composition. Jones *et al.* (1984) examined buildings housing young chicks that used wood chips as floor litter. They compared litters of different ages – one week old versus over a year old – and found that both total and respirable dust levels were higher in the building with old litter. Jones *et al.* (1984) described the old litter as essentially dry manure and suggested that it was responsible for the increased dust.

Madelin and Wathes (1989) compared deep litter and raised netting flooring in broiler houses, with the latter consisting of plastic netting raised 25cm above a concrete floor. The results showed that the concentrations of respirable and total dust were significantly higher in the rooms with litter than those with netting. Microscopic analysis of the dust showed that skin squames (flakes) accounted for the majority of the particles in both rooms. Fungal spores never accounted for more than 5 per cent of the total dust in the netted room, but concentrations of fungi increased rapidly within four weeks in the rooms with litter.

5.2.3 Effect of waste management

There have been few studies on the effect of waste management systems on bioaerosols in swine and poultry confinement buildings. Zhao *et al.* (2005) studied two swine buildings: one with a deep pit below a slatted floor and the other with a pull-plug shallow pit and outdoor lagoon manure storage system. The two waste management systems were very similar, but in the latter system the manure in the pit was regularly removed into a lagoon. The researchers found that the dust concentrations in the deep-pit barn were consistently higher than in the pull-plug lagoon system.

Venter *et al.* (2004) compared two types of waste management system in an automated chicken egg layer plant. The first system involved a central opening in the floor of each cage through which faecal matter automatically dropped to an open-air lower level, which was emptied every two weeks. The second system used a conveyor belt below each hen battery set, which removed the faecal matter daily. There was little difference in the total dust concentrations between the two waste management

systems. However, there were distinctive differences in the bioaerosol content. Aerosolised yeast was only found with the pit system whereas *E. coli* counts were much higher for the conveyor belt. It was suggested that this difference was probably due to the faecal waste being scraped off the conveyor belt, producing higher concentrations of aerosolised particles of faecal origin.

5.3 Summary – effects of ventilation & housing conditions on bioaerosol emissions

The actual building that the animals are being kept in can have a large impact on bioaerosol emissions. The growth stage of the animal can dictate what kind of building is used and in turn factors such as ventilation rates, feeding methods, waste management systems and type of bedding can vary. There may also be seasonal effects and this is particularly important when assessing the impact of ventilation rates.

The process of ventilating a livestock building has several roles:

- Ventilation rates, air movements and air quality can be affected by the building design itself
- Ventilation is used to maintain optimum conditions for the animals and the workers – for example, not too hot or too cold
- Performance of the system is often measured by how well it controls air temperature, relative humidity and air speed. It must also adequately remove gases, dust and microorganisms
- Ventilation is one process by which bioaerosols are cleared from the air – sedimentation, impaction and electrostatic precipitation also play a role
- Ventilation rates control the emission of airborne pollutants from the building and the system design has a major effect on the environmental impact of the building
- Ventilation rates normally range from 2 to 200 air changes per hour
- Natural and mechanical ventilation systems can be used and there are recommended rates for different animals and different seasons
- There is little agreement between researchers about the influence of ventilation on dust concentrations – there may be a relationship between increased air flow and reduced dust particles but it is not strong. The settling out of dust particles on different surfaces is more important than ventilation rate
- Total and respirable microorganism concentrations did not vary between naturally and mechanically ventilated pig finishing buildings

There are known to be seasonal effects on ventilation rates of livestock buildings:

- Most livestock buildings studied were enclosed with mechanical ventilation systems although some had windows that could be opened to let air in
- Different open air systems are used in subtropical countries for pigs – microbial concentrations are significantly lower in these systems than in the typical enclosed European versions

- Higher concentrations of dust and microbial concentrations have been found in winter in the European type pig buildings – possibly due to lower ventilation rates as windows/doors were shut to keep the heat in
- Airbourne dust and microbial concentrations increase as outside temperature decreases – although this relationship is not found if an internal heating system is used in pig buildings
- For poultry – the dust concentration in summer was half that found in winter in broiler houses even though the internal temperature was relatively stable – possibly due to increased ventilation in summer

Effects of housing conditions

- Feeding practices obviously differ between pigs and chickens but feed is either wet or dry and the feed type can affect dust concentration in livestock buildings – it is not always clear how feed type affects dust concentrations
- In one study dry feed is noted as a major contributor to airbourne dust levels in pig buildings whilst another stated that the type of feed had little impact on the daily average dust concentrations and the pigs themselves were major contributors
- Dust concentrations do increase during feeding
- Animal feed may act as a reservoir for fungi such as *Aspergillus flavus* and another study was able to distinguish moulds inside the building as different from those outside
- Adding oil/fat to the feed may decrease the amount of dust in pig buildings
- Specific feeding method: floor fed or trough feeding, restricted or freely available, indirectly affects dust concentrations – mainly due to how the activity of the pigs changes
- One study found that higher dust concentrations were found during restricted feeding but another found the opposite
- No references to feeding methods for poultry were found

Litter/bedding types used in raising pigs in particular has changed in recent years. In the past most pigs were kept on slatted floors over an open pit to collect the waste but recently more animals are being kept on an enclosed compost bed of peat or sawdust. Stocking densities are lower and workers are exposed to lower levels of ammonia etc. but the compost must be turned regularly

- Buildings using compost systems had airbourne microorganism concentrations 10-1000 times higher during turning of the compost when compared to traditional slatted floors. Fungal concentrations, especially those responsible for Farmer's lung disease were particularly high
- Greater concentrations of airbourne bacteria and respirable endotoxins are found if there is bedding. There was also a relationship between endotoxin concentration and humidity

For poultry the bedding used depends on whether they are laying hens or broilers. Laying hens are often kept in cages with no litter or on percherries with some litter. Broilers can have deep litter or be kept on netting over concrete floors.

- Floor litter is the main source of airbourne fungi in deep litter systems
- The older the litter the higher the respirable dust concentration
- Deep litter systems have significantly higher respirable dust concentrations when compared with plastic netting systems
- Fungal concentrations comprised around 5% of total dust in buildings with the netting floor but increased rapidly above this with deep litter systems within four weeks

The way animal wastes are managed can also impact in bioaerosol emissions but again the literature is not that extensive.

- For pigs there is a difference between a system using a deep pit below a slatted floor as opposed to a pull-plug shallow pit with outdoor lagoon where the wastes are regularly removed to the outdoor lagoon – dust concentrations were consistently higher in the system using a deep pit
- For poultry (laying hens) there is a difference between cages with openings where the waste fell through to a lower level which was emptied every two weeks and a second system where waste fell onto a conveyor belt and was removed daily. Although dust levels were similar for both systems, bioaerosol emissions did vary – airbourne yeast were only found with the pit system and *E coli* counts were much higher for the conveyor belt system

6 Occupational exposure & work activities – pig & poultry workers

6.1 Overview - occupational exposure of pig and poultry workers

The potential for adverse health effects from working in animal confinement houses was first investigated in the US in the late 1970s (Donham *et al.* 1977). Since then, numerous clinical and epidemiological studies have investigated the ill-health experienced by workers working in animal confinement houses. Most of these studies have been carried out by researchers in the US (for example, Donham *et al.* 1977, 2000, 2002), Sweden (Zhiping *et al.* 1996; Wang *et al.* 1997; Larsson *et al.* 2002), the Netherlands (Vogelzang *et al.* 1997, 1999, 2000), Denmark (Iverson and Dahl 2000; Radon *et al.* 2001), Norway (Melbostad *et al.* 1997, 2001, Eduard *et al.* 2001) and Canada (Kiryuchuk *et al.* 1998, 2003; Cormier *et al.* 2000). Most studies carried out to date have focused on swine and poultry workers. A summary of the results of the reviewed studies is included in Appendix 4.

Studies investigating the respiratory health effects associated with working in animal confinement houses have used a variety of study designs and markers of ill-health. Both cross-sectional designs (such as Melbostad *et al.* 2001), including case-control (such as Vogelzang *et al.* 1999), and longitudinal designs, including cross-shift (such as Donham *et al.* 2002) and cohort studies with varied follow-up (such as Iverson and Dahl 2000), have been used, where exposed groups are followed over time or compared to a reference group.

The reference groups included workers active in other job roles, such as more conventional animal farming (such as Radon *et al.* 2001) or in other agricultural or non-agricultural sectors entirely (grain workers, non-farmers; such as Kiryuchuk *et al.* 2003). A few studies employed a more straightforward panel or exposure study type approach, where the incidences of various clinical endpoints are documented without comparison to a reference or baseline (such as Jolie *et al.* 1998). Additionally, intervention-type designs have been employed, where exposures are systematically reduced to investigate their effects (such as Zhang *et al.* 1998).

Most studies have investigated reported cases of work-related respiratory symptoms (such as eye, nasal and throat irritation, wheezing, chest tightness, cough and phlegm, and muscle aches/pains) and decline in lung function (either cross shift or annualised). A number of studies have also investigated the effects of exposure on non-specific airway reactivity (such as Larsson *et al.* 2002) and on levels of inflammatory markers in peripheral blood and respiratory tissue (such as Wang *et al.* 1997). These markers of ill-health have been investigated by monitoring their occurrence over time or across groups or by measuring levels of exposure to the suspected causal agents, such as dusts, ammonia and endotoxin (Reynolds *et al.* 1996; Cormier *et al.* 2000).

The results of these published studies suggest that the ill health experienced by many workers is attributable to inhaling hazardous airborne agents in the workplace and is underpinned by a complex set of respiratory responses. Evidence indicates that these agents have an adverse effect on the large and small airways and on lung tissue. The

range of observed health outcomes suggests that irritant, toxic or allergic processes may be involved, although specific disease mechanisms are often not identified. In addition, because of the cocktail of agents that workers are potentially exposed to through their work, rarely are the health problems attributed to a specific causal agent. Acute, immediate, delayed and chronic respiratory responses have all been observed.

The pattern of respiratory symptoms that tend to be most reported are characteristic of chronic obstructive pulmonary disease (COPD), particularly bronchitis, which is commonly associated with increased airway reactivity. Workers have reported complaining of respiratory symptoms (such as chest tightness and wheezing) within 30 minutes to an hour of entering the confinement houses. However, a lag period of two hours or more is more typical. Most acute cases of disease tend to constitute acute (irritative) bronchitis or toxic pneumonitis, although in a small proportion of workers specific allergic mediated illness, characteristic of an immediate asthma response, may be apparent.

Allergens that are potentially present in animal houses and may elicit an allergic response include animal danders (animal hair, fur and feathers) and urine, grain dusts and microorganisms. Delayed responses, where symptoms initiate four to six hours after exposure, include organic dust toxic syndrome (ODTS), which is characterised by symptoms including fever, malaise, muscle ache/pain and headache, and late phase allergic responses. Raised specific IgE (immunoglobulin E) and IgG (immunoglobulin G) and positive skin prick tests to animal antigens have been documented in workers, suggesting immunological responses to antigen exposure (Brouwer *et al.* 1990; Zuskin *et al.* 1991).

The strongest evidence for adverse health effects of working in swine and poultry confinement houses comes from studies that have investigated large worker cohorts over time and have documented dose response relationships between lung function decline and level of exposure, both across work shifts and over the longer term. Dose response relationships have been most frequently observed for personal exposure to dust, endotoxins and ammonia. (Donham *et al.* 2000; Radon *et al.* 2001; see appendix for more information). However, several studies have failed to observe similar associations, perhaps due to the wide variability in the cocktail of hazards to which workers may be exposed.

Table 6.1 Acute symptoms of swine confinement workers

Symptom	Prevalence (%)
Cough	67
Sputum/phlegm	56
Scratchy throat	54
Runny nose	45
Burning/watering eyes	39
Headaches	37
Tightness of chest	36
Shortness of breath	30
Wheezing	27
Muscle aches/pains	25

Source: Taken from Donham (1993)

In a summary of published evidence, Donham (1993) estimated that approximately 60 per cent of employees working in animal confinement facilities had experienced symptoms of chronic bronchitis (25 per cent with heightened airway reactivity; see Table 6.1). Around 50 per cent had experienced symptoms of acute bronchitis and eye, nose and throat irritation, 30 per cent had experienced symptoms of ODTS and 20 per cent had experienced symptoms of chronic sinusitis.

Studies that have measured lung function as a health-endpoint (Reynolds *et al.* 1996; Kirychuk *et al.* 1998; Senthilselvan *et al.* 1997; Iverson and Dahl 2000) generally report deficits in forced expiratory volume in one second (FEV₁) of the order of 70–80 per cent of predicted values (those expected based on age, height and gender). They also reported mean declines in FEV₁ of 3–10 per cent over a shift, and excess annual declines in FEV₁ of around 20–30ml³. However, such generalised figures hide the typically wide variability in the findings from studies. This may be attributed to differences in the animal building environments and associated operations that are being investigated, as well as methodological differences between studies, such as differences in study populations and study power.

6.2 Effect of work activity on exposure to bioaerosols

Workers in swine confinement buildings tend to consist of employees or family members who undertake a variety of tasks under the direction of the farmer. Christensen *et al.* (1992) classified the work in swine buildings into nine separate tasks: (1) feeding the pigs; (2) sprinkling straw; (3) mucking out; (4) moving the pigs; (5) cleaning; (6) cutting tails; (7) surveillance; (8) weighing pigs; and (9) other operations. Similar tasks were associated with the work undertaken in swine confinement buildings by Donham (1993). He also included preparing feed and performing routine vaccination and treatment of the pigs as specific tasks. The study by Christensen *et al.* (1992) examined the distribution and range of time spent daily undertaking each task by a cohort of 26 farmers. The results are shown in Table 6.2.

Table 6.2 The distribution of time used for nine work tasks during a day's work in a swine building

Task	Mean percent of working day
Feeding pigs	11%
Sprinkling straw	7%
Mucking out	14%
Moving pigs	11%
Cleaning	4%
Cutting tails	21%
Surveillance	8%
Weighing pigs	2%
Other operations	22%
Total	100%

Source: Christensen *et al.* (1992)

It is clear from the results that larger proportions of time are spent on tasks such as mucking out pens and feeding and moving pigs, which are known to produce increased levels of dust and bioaerosol. However, no scientific studies examining the role of specific tasks in the formation of bioaerosols have been identified. Donham *et al.* (1977) interviewed 35 veterinarians who regularly worked in swine buildings and found that 32 had symptoms such as irritation of nasal passages and eyes, coughing and

³ In adults over the age of about 35, irreversible decline in FEV₁ over time is normal and is attributable to the effects of aging. Typical rates are of the order of around 30ml/year in non-smokers. Excess annual decline refers to annual decline in FEV in addition to that expected due to the effects of aging.

tightness of chest during periods of work on farms averaging seven hours per week. These symptoms are the same as those of affected workers in swine buildings.

Workers involved in the farming of broiler chickens can be divided into three specific professions: growers, catchers and hangers (also referred to as shacklers). There are also personnel involved in meat processing. A chicken grower is a farmer who raises chickens. The tasks of a grower in the chicken house include cleaning the drinkers, ensuring a continuous flow of water and feed, and collecting dead birds. Whereas poultry growers spend a comparatively short time in the confinement building (Lenhart and Olenchock 1984), chicken catchers and hangers are exposed to organic dust and other respiratory toxicants throughout most of their work shift.

Once a flock of chickens is ready for processing, the work cycle of a chicken catcher includes walking towards the chickens and lifting four or five birds in each hand, carrying the birds back to cages and loading the chickens into the cages for transportation by trailer truck to a processing plant. At the processing plant, chicken hangers or shacklers remove live birds one at a time from cages and hang them upside down by their feet in shackles (Nielsen and Breum 1995). Other tasks involved in chicken meat processing are plucking or dressing, eviscerating, trussing and packing.

Thelin *et al.* (1984) examined the airborne dust and endotoxin concentrations associated with the tasks undertaken by chicken catchers. The highest dust levels were recorded when young hens were placed into, and older hens removed from, cages. The highest endotoxin levels were associated with the loading of cages with layer hens. Lenhart *et al.* (1990) examined the exposure of six crews of catchers and reported that the crews working at night were less exposed to air contaminants than catching crews working during the day. Morris *et al.* (1991) undertook a survey of catchers' health and showed that more than eighty-five percent of the catchers had one acute symptom. However, no control group was examined.

Nielsen and Breum (1995) investigated the total dust, airborne micro-organism and endotoxin concentrations that catchers were exposed to by personal sampling of the air. Two methods of catching poultry were examined: the drawer method of loading cages and the truck method. The drawer method consists of loading birds into cages mounted on a rack standing on the floor. The catching crew consists of four catchers and a person who loads the racks onto a trailer using a forklift truck. The truck method involves loading the chickens into cages on a truck parked inside the confinement building. The catcher hands the birds over to a helper who loads the cages. Nielsen and Breum (1995) found that catchers using the draw method were exposed to higher concentrations of dust, microorganisms and endotoxin compared to workers using the truck method.

It has been previously stated (see Section 4.2) that greater bacterial concentrations are found in the shackling areas of poultry processing plants than in other areas. Only one study on the health of shacklers has been reported (Hagmar *et al.*, 1990), and it concluded that levels of organic dust and endotoxin were unacceptable.

Workers involved in egg production are also exposed to bioaerosols and the concentration is dependent on the type of layer house. Both Larsson *et al.* (1999) and Kirychuk *et al.* (2003) compared buildings containing caged layer hens with buildings where the birds are free to roam. Larsson *et al.* (1999) used naïve subjects in their study and reported a tendency towards stronger reactions in the building with freely roaming hens. In contrast, Kirychuk *et al.* (2003) compared the respiratory responses of poultry workers from free-to-roam-based operations with those from cage-based operations and found the health of the workers from cage-based operations to be poorer. A higher prevalence of cough, phlegm, wheeze and shortness of breath were reported by workers in cage-based operations compared to staff working with free roaming hens. The researchers suggested that the health differences between the two

groups of workers may be due to the different levels of microbial contamination within the different types of buildings. However, this is inconsistent with past studies (Takai *et al.* 1998; Seedorf *et al.* 1998a; Larsson *et al.* 1999) that have found higher concentrations of dust, microorganisms and endotoxin with free layer hens than with those in cages.

6.3 Summary – occupational exposure

The potential for adverse health effects from working in the intensive farming industry is well known and relatively well-documented. Most of the work has been done with pig and poultry workers.

The main health impacts include respiratory symptoms such as:

- eye, nasal & throat irritation, wheezing, chest tightness, cough, phlegm, muscle pain, headaches, decline in lung function

Causal agents investigated have included dust, ammonia and endotoxins and health effects are via inhalation of these airborne particles.

Most respiratory symptoms are similar to chronic obstructive pulmonary disease (COPD) such as bronchitis, chest tightness and wheezing, sometimes an asthmatic response occurs. Symptoms can occur within 30 minutes of going into the livestock building but normally occur after two hours or more.

Asthmatic and allergenic health effects can have many causal factors that includes exposure to microorganisms but also includes exposure to animal fur, feathers or hair, urine and grain dusts.

There is evidence of a dose response relationship between lung function decline and level of exposure to dusts, endotoxins and ammonia in some studies but not all. Symptoms experienced varied but for example 50 per cent reported acute bronchial, eye, nose and throat symptoms.

Although there is evidence to show that worker health can be impacted by intensive farming there is also variation in the type of activities they do. Tasks associated with pigs can be divided into about nine separate things with most time being spent mucking out pens, feeding and moving pigs. All these activities are known to be associated with high levels of dust and bioaerosol emissions. No work has been done on the bioaerosol production rates for defined tasks in pig production.

A similar picture is found for poultry growers with range of tasks such as feeding and watering. Poultry growers spend less time in the buildings than the poultry catchers and shacklers who spend most of the time in the buildings – levels of exposure to bioaerosols obviously varies widely. Some work has been done with chicken catchers, for example:

- highest dust levels were found when hens were put in to and older hens removed from the cages
- highest endotoxin levels were found when layer hens were put in to cages
- crews working at night had lower levels of exposure than those working during the day
- more than 85% of catchers had more than one acute symptom

- The method of catching affects level of exposure to microorganism and endotoxins – the 'draw method' results in higher exposure than the 'truck' method
- Bacterial concentrations are highest during shacking operations, levels of dust and endotoxin can be unacceptable

The way the birds are kept can have an affect on the levels of bioaerosols that workers are exposed to but the differences in health effects are not clear:

- In one study greater health effects were found with free-roaming birds but another showed greater effects with caged birds
- We know from other studies that higher concentrations of dust, microorganisms and endotoxin are associated with uncaged layer hens rather than caged birds

7 Use and effectiveness of dust and particulate controls

There are four approaches that can be used for dust and particle control:

- prevent particle formation
- prevent particle release
- remove suspended particles from enclosed work spaces and
- isolate workers from dust clouds in work spaces

A series of practical techniques for dust control have been assessed including:

- vacuum cleaning or the use of cyclones
- ionisation and electrostatic air cleaning
- fogging, showering, and spraying the animals with vegetable-based oils
- biofilters
- respiratory protective equipment

7.1 Vacuum cleaning

Nilsson (1979) first reported that vacuum cleaning feed passages and pen partitions at least once a week improves the work environment. However, using mechanical air cleaners to remove large amounts of dust is not cost effective. Equally, using vacuum cleaners to remove surface dust is likely to increase the concentration of airborne dust. Traditional cyclones, which use the principles of centrifugal force to separate particles in air streams, have been studied since the early 1930s. The application of these cyclones is largely limited to material separation industries rather than air cleaning. This is primarily because of two limitations: high energy consumption and low dust separation efficiency for small particles. Zhang *et al.* (2005) designed a cyclone-based apparatus incorporating a fine mist scrubbing system, which removed more than 90 percent of all dust and could be run at low pressure, leading to reduced running costs.

7.2 Use of electrostatic scrubbers

As an overall dust control measure in pig houses, negative ionisation appears to have only a limited ability. Czarick *et al.* (1985) and Veenhuizen and Bundy (1990) demonstrated dust reductions in pig barns of 31 per cent and 67 per cent, respectively. However, despite there being a variety of negative ionisation treatments to reduce airborne dust in barns, most are not practical in areas where dust levels are relatively high, such as the caged layer rooms used in poultry production.

In 2000, Mitchell *et al.* first reported the effective use of an electrostatic space charge system (ESCS) against both artificially- and naturally-generated dust in a caged layer room, reducing them by 72–91 per cent and 52 per cent, respectively. Mitchell *et al.* (2000) suggested that the increased effectiveness against artificial dust was due to the higher concentrations of dust produced by a smoke pencil compared to that generated

by the hens in the caged layer room. The smoke pencil produced dust in the size range of 0.3–5µm. Further studies by Mitchell *et al.* (2002) and Mitchell and Waltman (2003) have demonstrated that the ESCS can reduce the total aerobic bacteria and enterobacteria content of bioaerosols in egg hatching cabinets by 85 per cent and 93 per cent, respectively. This can lead to a reduction in the number of chicks contaminated with Salmonella. The use of the ESCS also resulted in a 64 per cent mean reduction in Gram-negative bacteria when utilised in broiler breeding rooms (Richardson *et al.* 2002).

7.3 Use of spraying – fogging, showering

Fogging is undertaken to increase the dust particle volume by forming aggregates of dust and water droplets. The air feels fresh for a while, but the method is expensive and the fogging must be carried out six or seven times a day to be effective (Gustaffson 1997). Zhu *et al.* (2005) reported that the use of a fogging system utilising water droplets of 20–50µm in diameter in conjunction with a cooling fan reduced the average airborne dust concentration by 75 per cent, from 7.94+/- 4.67mg/m³ to 1.98 +/- 1.8mg/m³, during the feeding period of pigs. The main disadvantage of this technique was that, in order to achieve a 75 per cent reduction in dust, the cooling fan and fogging system was operated continuously from early morning to the middle of the night. It would therefore require unacceptable quantities of water to operate such a system. Chang *et al.* (2001a) suggested that the routine spraying of pigs with water to reduce their body temperature would enhance the reduction of airborne contaminants, but may also provide high moisture for microbial growth and multiplication. These authors suggested that the increase in moisture may lead to high microbial counts in farrowing and finishing stalls.

Showering the passages and the equipment with water should prevent the settled dust from whirling up when the activity of the animals increases. Showering just before weighing pigs or catching poultry is recommended. Banhazi *et al.* (2002) reported that spraying the partially slatted floor of a pig facility with a 50:50 mixture of canola oil and water led to a reduction in the concentration of both inhalable and respirable airborne particles in the airspace immediately after spraying. The use of canola oil sprinkling to control dust in pig facilities is attractive to the swine producer because it is relatively inexpensive, as well as practical and easy to use. Other past studies have shown that spraying a mixture of 5 per cent rapeseed oil and 95 per cent water in swine buildings reduced dust mass concentrations by 60–95 per cent (Takai *et al.* 1993).

Zhang *et al.* (1994, 1995, 1996) examined alternative oils, as well as the effects of various sprinkling pressures and temperatures. They determined the critical pressures and temperatures to prevent misting during sprinkling and proposed optimal sprinkling frequencies and quantities for swine buildings. Senthilselvan *et al.* (1997) examined the benefits to worker health of spraying oils and showed that sprinkling canola oil reduced the acute health effects experienced by healthy naïve subjects exposed to airborne contaminants in swine buildings. In Denmark, tests have been conducted in spraying animals to reduce the formation of dust particles from skin cells and dandruff. An 80 per cent reduction in dust concentration and a four-hour effect for the treatment were reported (Takai *et al.* 1986).

7.4 Use of biofilters

The majority of internal air cleaning devices consist of particulate air filters, while some also possess odour-absorbing media downstream of the filter. The filtration media should have a point of contact with the dust particles to remove them from the air. This

contact process quickly accumulates dust onto the media, which requires frequent maintenance or replacement.

In 1975, Avens *et al.* reported a reduction in the microbial content of the air inside chick hatching cabinets following the filtering of recycled air. In 1981, Carpenter demonstrated the first use of an internal filter unit for use in intensive livestock buildings, with a further development of the design subsequently being used in a swine building (Carpenter 1982). This author suggested that in a well-mixed equilibrated system, particle removal by ventilation can be regarded as being indistinguishable from particle removal by filtration. Thus, if the air capacity of the filter is equal to that of maximum ventilation, dust concentrations should be reduced at all times by the order of magnitude achievable with maximum ventilation. For pigs and poultry, this filtration air capacity is likely to be a realistic compromise between filtration costs and the reductions in dust levels that can be achieved.

Biofilters have more recently been considered for filtering exhaust air and to prevent microbes from leaving intensive farming buildings and entering the outside environment. Seedorf and Hartung, (1999) reported that preliminary results from a one-year study in two swine buildings showed that a biofilter can reduce the number of particles in exhaust air by 79–96 per cent. It also reduced the amount of thermotolerant fungi by 71 per cent.

Studies by Martens *et al.* (2001) compared the effect of different filter materials, including commercially-available Biochips, commercially-available Biocontact filter pellets covered with bark, a coconut/peat mixture, a wood chip/bark mixture and compost, on the exhaust air emitted from a swine confinement building. These authors found clear differences between the different filter materials. Numbers of airborne culturable bacteria were decreased by 70–95 per cent and the total counts of bacterial cells fell by 25 per cent to >90 per cent, but biochips and compost were poor at removing both cultivable and total bacteria. The total amount of fungal cells were reduced by at least 60 per cent, but Martens *et al.* (2001) found that when using the bark/wood mixture, the Biocontact pellet and compost the percentage of culturable moulds in the air was higher after passing through the biofilters. Airborne endotoxin and microbial volatile organic compounds were effectively reduced by at least 90 per cent by all the tested biofilters. The results of the studies of Martens *et al.* (2001) are summarised in Tables 7.1 and 7.2.

Table 7.1 Concentrations of different microbial bioaerosol parameters in the waste of a swine confinement building and behind different connected biofilters (Martens *et al* 2001)

	Conc in waste air	Filter Type				
		Biochips	Coconut fibre / peat mixture	Chopped bark & wood	BioContact filter pellets & bark	Crude compost
Culturable bacteria (cfu/m ³)	1.1 x 10 ⁵	3.9 x 10 ³	2.6 x 10 ³	8.5 x 10 ²	1.2 x 10 ³	2.0 x 10 ³
Total bacteria cells (tbc/m ³)	4.1 x 10 ⁶	1.7 x 10 ⁶	<8.2x10 ⁵	<3.1 x10 ⁵	<7.1x 10 ⁵	<6.2 x 10 ⁵
Culturable fungi (cfu/m ³)	2.2 x 10 ²	3.3 x 10 ¹	3.7 x 10 ¹	2.5 x 10 ²	5.2 x 10 ²	1.8 x 10 ²
Total fungal cells (tfc/m ³)	5.4 x 10 ⁵	<8.7 x 10 ⁴	<1.2x10 ⁵	<8.7 x 10 ⁴	<8.7 x 10 ⁴	<8.7 x 10 ⁴
Airborne endotoxin (EU/m ³)	792.5	19.9	11.9	7.6	32.1	42.4

Table 7.2 Emission rates (units per livestock unit and time) of microbial bioaerosol parameters in waste air and air cleaned by biofilters made of different filter material (Martens *et al* 2001)

	Conc in waste air	Biochips	Coconut fibre / peat mixture	Filter Type		
				Chopped bark & wood	BioContact filter pellets & bark	Crude compost
Culturable bacteria (cfu/LU/h)	3.4×10^7	1.0×10^6	4.1×10^5	1.7×10^5	4.9×10^5	9.4×10^5
Total bacteria cells (tbc/LU/h)	1.3×10^9	5.3×10^8	$<2.8 \times 10^8$	1.4×10^8	$<2.9 \times 10^8$	$<2.6 \times 10^8$
Culturable fungi (cfu/LU/h)	6.6×10^5	1.9×10^4	2.2×10^4	1.6×10^5	3.0×10^5	1.1×10^5
Total fungal cells (tfc/LU/h)	2.0×10^8	$<3.0 \times 10^7$	$<4.9 \times 10^7$	$<3.5 \times 10^7$	$<3.6 \times 10^7$	$<3.7 \times 10^7$
Airborne endotoxin (EU/LU/h)	6.4×10^7	1.9×10^5	8.8×10^4	8.3×10^4	4.0×10^5	5.8×10^5

LU = Livestock unit

7.5 Use of respiratory protective equipment

In a 1993 US study, only 30 per cent of swine confinement workers reported using dust masks when working inside a barn (Zejda and Dosman 1993). In 1995, Pickrell *et al.* examined the degree of dust protection offered by respiratory masks when worn in swine confinement buildings. Respiratory protection limited total dust exposures to <25 per cent of the non-masked values with two-tie masks and to <50 per cent with one-tie masks. The number of respirable particles was reduced to <58 per cent of the non-masked values with two tie masks.

More recently, Dosman *et al.* (2006) have reported the results from a cross-over trial to examine the human health effects on naïve volunteers of wearing a disposable N-95 particulate respirator in a swine barn. The N-95 particulate respirator consists of a disposable mask with two straps and a nose clip and most closely resembles a P2 mask in the UK. The researchers found that the use of the mask virtually eliminated acute respiratory symptoms, including shift changes in FEV and responses of IL-6 (interleukin-6) in serum and nasal lavage fluid. Furthermore, it has been demonstrated that educational intervention can increase the use of respiratory personal protection (Gjerde *et al.* 1991).

7.6 Summary of control strategies

There is no one strategy that is always better than the others. Each control strategy is more effective in certain situations than others and all need to be assessed on a site-specific basis.

Vacuum cleaning of feed passages and pen partitions:

- Good at reducing dust concentrations
- Expensive for large amounts of dust
- Removal of surface dust is likely to increase airbourne dust concentrations

- Cyclones would be more effective at cleaning the air but have high energy consumption and are not so effective for small particles

Electrostatic scrubbers:

- Negative ionisation in pig houses has limited effectiveness
- Not suitable for areas with high dust levels such as around caged laying hens
- Use of Electrostatic space charge system (ESCS) has been more successful with a significant reduction in total bacteria in egg hatching cabinets and a reduction in Gram-negative bacteria in broiler breeding rooms

Spraying with water/oil:

- Fogging – increases dust particle volume (aggregate of dust & water droplets), works for a short time but is expensive (needs to be done 6-7 times per day) uses too much water/energy. High moisture content could lead to increased microorganism concentrations
- Showering – using water/oil on passages and equipment to prevent settled dust becoming airborne at times of high animal activity such as weighing pigs or catching poultry. Mixture of canola oil and water can reduce inhalable and respirable dust concentrations, is relatively cheap and easy to use, it also reduces acute health effects in workers

Use of air filters and in particular biofilters:

- Usually consist of an internal particulate air filter and some can absorb odour, there are many different types of filtration media
- Studies show that filters can be very effective in reducing airborne microorganism concentrations in pig and poultry buildings. Biofilters can reduce the number of particles emitted from pig buildings by 79 - 96 per cent and fungi by 71 per cent
- There is a balance between filtration costs and the amount of dust removed
- There is a difference in effectiveness of different filter materials – biochips and compost are poor at removing cultivable and total bacteria. Another study found that culturable mould concentrations went up after filtration with bark/wood mixtures, Biocontact pellet and compost
- Airborne endotoxin and microbial volatile organic compounds are reduced by 90 per cent by all tested biofilters

The use of respiratory protective equipment such as dust masks in intensive pig farming is generally low even though they do reduce exposure. In one study the use of a particular type of disposable mask (N-95 particle respirator) nearly eliminated all acute respiratory symptoms.

8 Bioaerosol emissions from livestock buildings

The emission of pollutants from intensive farming activities into the wider environment is recognised to be a problem which may have potential adverse health effects. Previous sections have described factors which can affect bioaerosol production and the potential impact that may have on human health *inside* the building. These factors include: animal growth stage, activity (of animals and workers), housing conditions and building ventilation rates. The Environment Agency under the IPPC regime must ensure that any regulated activity uses the Best Available Technique to control wider impacts on the environment. In the case of intensive agriculture this means giving consideration to potential bioaerosol emissions ‘off site’ and any effects that may have on the health of people living nearby.

8.1 Dust emission rates

Dust in exhaust air from pig and poultry houses may provide a favourable environment in which pathogens can survive and be transported over long distances to other farms or neighbouring residential areas. Nevertheless, published research into the actual distances that dust can travel and pathogens can survive is limited.

A study by Takai *et al.* (1998) of dust emission rates from swine buildings and poultry houses in four northern European countries found that the type of poultry and the growth stage of pigs can influence the emission rate from the respective confinement buildings. Dust emission rates (mg/h) were estimated from the product of the mean daily dust concentration (mg/m³), which was measured near the air outlet of the facility, and the daily mean ventilation rate (m³/h) and expressed per livestock unit (500kg body weight). The carbon dioxide balance method was used to estimate the ventilation rate. Table 8.1 shows the emission rates as determined by Takai *et al.* (1998) for pigs according to age and for different types of poultry.

Table 8.1 Predicted mean inhalable and respirable dust emission rates on a 500kg live weight basis from swine buildings and poultry houses

Emission rates (mg/hour)	Swine			Poultry		
	Sows	Weaners	Fatteners	Layers: perchery	Layers: caged	Broilers
Inhalable dust (England)	133	687	728	1771	872	6218
Inhalable dust (Holland)	151	1309	418	4340	398	4984
Inhalable dust (Denmark)	949	1364	747	3131	642	1856
Inhalable dust (Germany)	453	724	532	ND	633	2805
Respirable dust (England)	31	60	103	467	161	706
Respirable dust (Holland)	18	122	40	682	46	725
Respirable dust (Denmark)	141	51	63	637	82	245
Respirable dust (Germany)	33	69	34	ND	24	394

ND = Not done
Source: Takai *et al.* (1998)

Takai *et al.* (1998) described a seasonal effect on inhalable dust emission rates, which were significantly higher in summer than winter. However, there was no seasonal effect on the emission of respirable dust from the same facilities. Takai *et al.* (1998) suggested that the respirable dust generation rates are possibly independent of season, despite the wide difference in ventilation rates for summer and winter. Hartung (1998) reported that the emission rate for respirable dust from swine buildings is approximately 60mg/h and that the emission rate from poultry houses is nearly 300mg/h, related to 500kg live weight of the animals.

8.2 Microorganism and endotoxin emission rates

In 1998, Seedorf *et al.*, who had worked with Takai *et al.* on the same survey of livestock buildings in northern Europe, reported the emission rates of microorganisms and endotoxins from swine buildings and poultry houses according to the age of the pigs and the type of poultry. Emission rates were determined from the product of the ventilation rate and the indoor concentrations of microorganisms or inhalable or respirable endotoxin, respectively. Emission rates were determined as an average over 24 hours and described as Log cfu/h or $\mu\text{g/h}$ per 500kg live weight, respectively. Figure 8.1 shows the emission rates of microorganisms and Table 8.2 shows the mean emission rates of endotoxin (Seedorf *et al.* 1998).

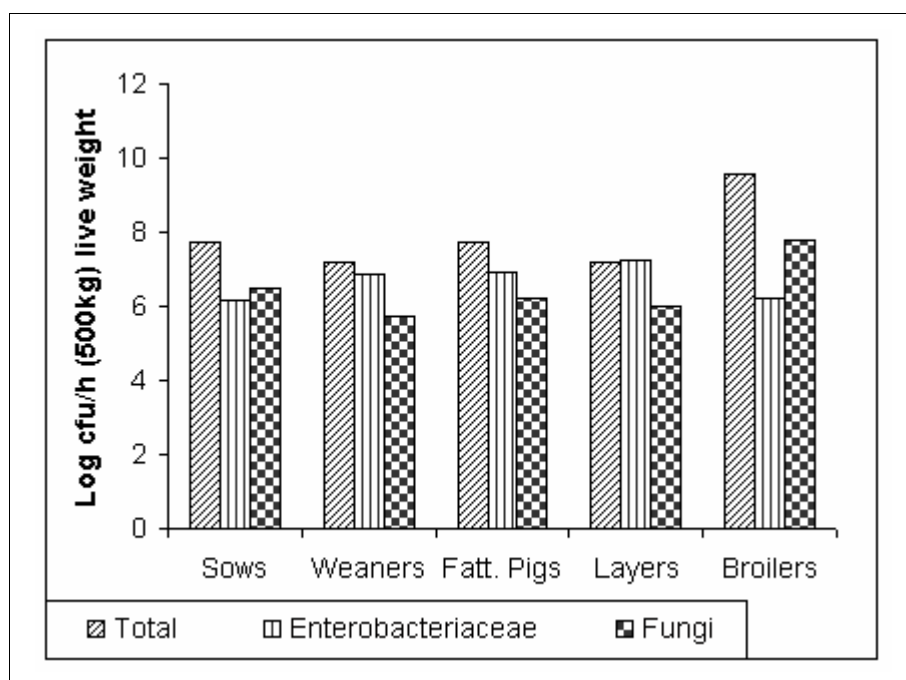


Figure 8.1 Emission rate of microorganisms in buildings housing the above livestock (Seedorf *et al* 1998)

Table 8.2 Mean emission rates of inhalable and respirable endotoxins over 24h for different pig and poultry types (Seedorf *et al* 1998)

Emission Rate µg/hour (500kg live weight)	Swine			Poultry	
	Sows	Weaners	Fatteners	Layers	Broilers
Mean Inhalable Endotoxin	37.4	66.6	49.8	538.3	817.4
Mean Respirable Endotoxin	3.7	8.9	5.2	38.7	46.7

The data clearly showed that the highest emission rates of total microorganisms, fungi and endotoxin were observed from broiler houses.

8.3 Bioaerosol emissions and distance from source

Seedorf and Hartung (2000) calculated bioaerosol emissions on the basis of the ventilation rate and the indoor concentration. As microorganisms are not inert, the biological half-life period of specific organisms was taken into account within the emission calculations. However, in the UK, the Environment Agency does not take the half-life of microorganisms into consideration, due to their toxic and/or immunogenic potential. Seedorf and Hartung (2000) calculated that, on a theoretical basis, broiler houses had the highest average emission rates. Compared with emission rates from other animal types, the release of total bacteria was more than 100-fold higher. However, the reality is that many factors, including the presence of obstacles such as trees and weather conditions, can have considerable influence on the airborne distribution of a bioaerosol.

Schulz *et al.* (2005a) investigated the emission of bioaerosols from a naturally-ventilated broiler barn and measured their concentration in front of a nearby dwelling. There was 'considerable emission potential of broiler houses for microorganisms and endotoxin, especially in the last weeks of the fattening period'. However, concern was raised that other sources of bacteria and endotoxin may have influenced the results. It was suggested that staphylococci be used as an indicator for bacterial emissions, and recommended that the influence of topographical structures such as buildings and trees on the spread of bioaerosols should be considered. In none of the above studies did the authors report the distances that these particles travelled through the air outside the animal buildings.

Studies conducted over a twelve-month period by Hartung (1992) showed that the distances travelled by fungi and bacteria were greatly influenced by season. Concentration was a greater influence on the distance travelled by bacteria, with the highest recovery rates 150–250m from livestock buildings. Platz *et al.* (1995) reported concentrations of airborne bacteria approximately 100m from swine buildings of 1700cfu per m³ in winter and 930cfu per m³ in spring.

In 1997, Hartung *et al.* reported preliminary field measurements of endotoxin concentrations at 50–115m downwind of a swine building, where the concentrations were 60ng/m³ and 15ng/m³, respectively. Further tentative experiments using high volume sampling and a Lidar technique around a swine building revealed distinctly higher concentrations of particles and endotoxins 115m downwind of the building compared with the reference sampling point upwind (Hartung *et al.* 1998). In contrast, Reynolds *et al.* (1997) did not observe endotoxin concentrations in excess of the detection threshold of 4EU/m³ at a distance of 60m from a swine building.

A study by Kollner and Heller (2005, 2006) measured the microbial content of air both upwind (background) and downwind of a pig-fattening establishment, at distances of up to 560m. They found that, compared to background values, the concentration of fungi and endotoxins were not elevated in the surrounding area. However, the total bacteria count, and staphylococcus in particular, proved to be good guide parameters for measuring the biological emission load resulting from an intensive swine confinement building (Kollner and Heller 2006). Similar results were reported by the Hanover Veterinary College (Tierärztliche Hochschule Hannover) on poultry farms (Schulz *et al.* 2005).

Kollner and Heller (2006) found that microbial concentrations measured downwind of the farm were all generally at a relatively low level. Even in the immediate vicinity of the farm, the measured concentrations were nowhere near as high as those measured at workplaces. They were also below the concentrations reported in the vicinity of composting plants by Heller and Rabe (2001) and Herr *et al.* (2004). However, Kollner and Heller (2006) reported that all the concentrations measured downwind for total bacteria count and staphylococcus, without exception, exceeded the background concentrations measured upwind. Whereas the concentrations continued to decrease at distances further than 200m from the emission point, there were no clear differences in the concentration levels at the measurement points closer to the farm. In contrast, in 2005, Kollner and Heller measured the maximum emission of total bacteria and staphylococci to be within 50–75m of the source.

Kollner and Heller (2006) suggested that the lack of variation in concentrations within 200m of the farm could be because it was constructed in such a way that sedimentation of the bioaerosols was not possible in the first 50m, meaning that it was not possible to measure the entire bioaerosol content. The authors gave the example of a measurement point located 50m away from the emission point in the swine building. This point was only a few metres away from the end wall of the swine building in the windward direction. Overall, Kollner and Heller (2005, 2006) reported that bioaerosol concentrations were markedly higher than background at a distance of 200m away from the facility. Further analysis of the data suggested a dispersal range of 420m for total bacteria and staphylococcus.

Also in 2006, Green *et al.* measured the levels of bacteria upwind and at various distances downwind of a swine confinement building in the US using two-stage Andersen samplers. This was done to determine the optimal positioning of future intensively farmed swine buildings in relation to residential areas. The researchers found a marked increase in the airborne bacterial concentration within the swine building, compared to 25m upwind of the facility. A steady decrease in airborne bacterial concentration was reported downwind for approximately 150m. These authors therefore concluded that the optimal placement of a swine confinement building would be at least 200m from a residential area.

There are far fewer studies of the distances bioaerosols can travel from poultry houses. In 1987, Muller and Weiser calculated the travel distance of viable bacteria from a laying hen house to be 200–300m downwind. A more recent study of emissions from poultry houses by Schulz *et al.* (2005b) reported measurements of staphylococcus at a distance of 333m from an externally-ventilated poultry house and 477m from a mechanically-ventilated poultry house. These concentrations were significantly higher than the background bacterial concentrations in uncontaminated rural areas.

8.4 Summary – key factors influencing bioaerosol emissions outside of buildings

There is evidence that pig and poultry buildings do emit bioaerosols. We know what is likely to be contained in those bioaerosols and what can influence that composition (housing conditions etc.). However, it is less clear how those bioaerosols emitted from intensive agriculture activities behave once they have been released from the livestock building, in particular what distance they are likely to travel.

Factors that can influence bioaerosol emissions from livestock buildings include:

- Animal – type and growth stage – dust emission rates are generally greater for layers as opposed to broilers and for pigs being fattened rather than sows or weaners. Overall the highest emission rates for total microorganisms, fungi and endotoxins are from broiler houses (more than 100 fold higher than other emission rates)
- Building type – a critical factor is ventilation rate and whether this is natural or mechanical ventilation - this is dependant on what the building is being used for – pigs or poultry, sows or weaners, broilers or layers for example. Staphylococcus has been found in another study at 333m from a naturally ventilated poultry house but 477m from a mechanically ventilated building.
- Seasonal effects & dust emissions – inhalable dust emission rates are higher in summer than winter but this is not reflected in respirable dust rates from the same facilities – respirable dust generation is possibly independent of season
- Bioaerosol concentration & distances travelled – e.g. one researcher found that airbourne bacteria concentration is highest 150-250m from livestock buildings. Another found that bioaerosol concentrations were 'markedly higher than background levels 200m away from the site with a dispersal range for total bacteria and staphylococcus of 420m.
- Seasonal effects & bioaerosol concentration - the distance bioaerosols travelled from a facility is affected by season when measured directly (as opposed to measuring dust emission rates). Concentrations of airbourne bacteria from swine buildings are higher in winter than in spring 100m from the building
- Local environmental conditions e.g. trees, other buildings – can have considerable influence over the airbourne distribution of bioaerosol but is difficult to predict and investigate
- Wind direction – the evidence is not so clear cut for bioaerosols as a whole e.g. researchers found that fungi and endotoxin concentrations were not elevated downwind of livestock buildings (compared to upwind) but total bacteria was (and in particular staphylococcus). This held for pig and poultry buildings. In general microbial concentrations downwind of livestock buildings are low and much lower than concentration inside the buildings but they are still above background levels.

9 Summary & conclusions

9.1 Summary of findings

The Environment Agency under the IPPC regime is responsible for regulating intensive farming of pig and poultry. In terms of impacts on health we need to understand the potential impact of emissions from those intensive agriculture activities in relation to other bioaerosol generating activities such as composting. This report has focused on intensive farming of pig and poultry and consists of a critical review of published literature on bioaerosols and dust from intensive livestock agriculture and potential human health effects.

Intensive farming of pig and poultry is often characterised by animals being housed indoors, in controlled environments and at high stocking densities. This type of agriculture is increasing globally with a related increase in bioaerosols emitted to the wider environment (section 1.2).

Bioaerosols are made up of non-microbial and microbial constituents and can be simply defined as particles of biological origin that are suspended in the air. Typical constituents include: bacteria, fungi, allergens, bacterial endotoxins, mycotoxins, peptidoglycans, pollen and plant fibres (Table 1.1). In recent years there has been increased recognition that exposure to bioaerosols can have an adverse health effect and in the context of intensive farming there are three main sources that make up the dust found in livestock buildings:

- Animals themselves – e.g. bacteria on shed skin/fur/hair/feathers, in urine & faeces
- Feed – an important source of airbourne dust especially during distribution, it can also act as a reservoir for fungi
- Bedding/litter – deep litter and slurry stores provide an ideal environment for some microorganisms

The dust found in pig and poultry buildings is made up of particles that vary in size and can be measured as total, inhalable or respirable dust concentration depending on size and impact on the respiratory system. The larger dust particles (i.e. visible particles) tend to settle out of the air first but do contribute to total dust concentrations. Dust particles of <100µm are small enough to be inhaled but are filtered out by the nose. Particles <10µm get trapped in the lung itself and are called respirable dusts. Very small particles (1-5 µm) can form an aerosol in the air. Most microorganisms in livestock buildings are attached to these smaller dust particles and therefore have the potential to affect human health as bioaerosols.

This literature review focused on the microbial content of bioaerosols emitted from intensive pig and poultry buildings. The constituents of a typical bioaerosol emitted from intensive agriculture vary depending on the animal being farmed and how it is being kept but are mostly (Section 2):

- Bacteria – Gram-negative bacteria include *Enterobacter*, *Acinetobacter*, *Moraxella*, *Pseudomonas*, *E coli*, Gram-positive bacteria include *Enterococcus*, *Staphylococcus*, *Streptococcus*, *Bacillus*, *Aerococcus* & *Micrococcus*. Majority of bacteria in bioaerosols are Gram-positive (especially Enterococci), less than 25% are Gram-negative

- Endotoxins (products of Gram-negative bacteria) – almost always found in pig and poultry buildings
- Fungi – most common include *Aspergillus*, *Scopulariopsis*, *Pencillium*, *Geotrichum*, *Mucor*, *Cladosporia* & *Fusarium*. Yeasts are also common

There tends to be a wider spectrum of fungal and bacterial species in poultry houses when compared to pig buildings. Common to both include:

- Bacteria – *Bacillus*, *Staphylococcus*, *Streptococcus*
- Fungi – *Scopulariopsis*, *Cladosporia*, *Mucor*

There are a wide variety of detection and sampling techniques than can be used for bioaerosol assessments (section 3). There are advantages and disadvantages to all methods and site-specific factors must be taken into account when designing a sampling methodology. The most widely used techniques for assessing dust and/or airbourne microbial load are:

- Impaction – e.g. the Andersen impactor, good for culturable microorganisms, no use for dust/particulate sampling, costly, short run periods
- Impingement – e.g. all-glass-impingers (AGI) good for culturable & non-culturable microorganisms, no use for dust/particulate sampling, low cost, can be run for long periods
- Filtration – e.g. personal cyclone samplers – useful for all types of analysis, low cost, can be used for extended periods but mainly for indoor use – standard method for respirable dust. IOM samplers useful for similar aspects and are standard for inhalable dust. Partisol samplers can be used for dusts and microorganisms but are costly and fixed point – standard for PM₁₀ and PM_{2.5} dust monitoring

Although the choice of bioaerosol detection method is critical to a successful assessment there needs to be an understanding of what is being assessed. In designing a sampling and monitoring strategy to assess bioaerosol emissions from intensive agriculture one of the most critical factors is the growth stage of the animal. This is directly linked to the type of building they are kept in and how the animals are managed day-to-day. The activity levels of the animals as well as the stocking density are also important (Section 4).

For pigs, nursery and farrowing buildings tend to hold a lot of animals that are more active and easily disturbed when compared to fattening and finishing buildings but the effect on bioaerosol concentrations is not always clear (Section 4.1.1):

- Some studies found higher dust levels in nursery/farrowing buildings and others found higher levels in finishing buildings
- There is some agreement such as the major constituents of dust from all pig buildings is grain particles and dried faecal matter
- Respirable dust concentrations are higher in nursery/farrowing buildings (as are total dust and endotoxin concentrations in another study)

For poultry, the type of building and the impact that has on bioaerosol emission varies depending on what the birds are being kept for – laying hens (caged or not) or broilers (section 4.1.2).

- For laying hens, uncaged birds have much higher inhalable dust concentrations, broilers have high concentrations of inhalable and

respirable dust, microorganisms and endotoxins and concentrations increase with bird age and weight

- The type of bacteria and fungi making up the bioaerosol varies as the birds get older

When comparing bioaerosol emissions from pig and poultry facilities there are some differences in dust, microbial and endotoxin concentrations (but some of the evidence is contradictory, section 4.1.3).

Dust concentrations:

- In one study total and respirable dust concentrations were higher in pig than caged layer hen buildings. Another study found inhalable and respirable dust concentrations were higher for the poultry buildings with broilers being highest of all

Microbial concentrations:

- Highest concentrations of total airbourne bacteria were found in broiler houses, with pigs and laying hens being similar, plus there was little difference between sows, weaners and fattening pigs. For Gram-negative bacteria this was reversed with the highest concentrations in pig buildings, then laying hens and finally broiler houses. But another study found the highest microbial concentrations in poultry buildings and this included the Gram-negative bacteria
- Fungal concentrations were slightly higher in poultry buildings, with daytime concentrations in broiler houses being higher than laying hens or pigs but at night levels dropped. Laying hens contained lower levels of fungi than pig buildings (but unclear whether they were caged or not). Sow buildings have higher fungal concentrations than weaners or fattening pigs

Endotoxin concentrations:

- Concentrations of airbourne endotoxins were much higher in caged laying hens than pig buildings and three times higher in poultry buildings as a whole
- Layer hens have highest endotoxin concentrations during the day, broiler houses at night
- Weaner pig buildings had higher endotoxin concentrations than fattening pigs with sow buildings having the lowest – this is opposite to concentrations of Gram-negative bacteria found in the same study

What the animals are doing and how active they are can affect dust concentrations and bioaerosol emissions (section 4.2):

- For pigs - activity rates vary depending on the growth stage - increased dust & endotoxin concentrations are sometimes found in nursery buildings as opposed to fattening units (possibly due to greater activity and higher stocking rates in the younger animals).
- Dust concentrations normally increases during weighing and feeding and dust levels are higher during the day as opposed to the night (when many more animals are not moving around so much)
- For poultry - dust concentrations (inhalable and respirable) are higher for broilers when compared to laying hens in cages and on perches.

- Significantly greater airborne bacterial concentrations are found in broiler houses when compared to laying hens and there little or no difference between night and day for broilers but not for laying hens
- Comparing pig and poultry buildings, airborne bacterial concentrations increase fastest in a broiler house when starting from a clean empty building

The effects of stock density are closely related to animal activity (section 4.3):

- In pigs, the amount of dust produced in the building is proportional to the number of animals and increases with bodyweight. The ventilation system can also be affected by high dust levels

The way the animals are kept and managed can also have a large impact on the bioaerosol emissions from intensive agriculture. The way the building is ventilated, how the animals are fed and watered and what bedding is used are all important factors. There may also be seasonal effects (section 5).

Ventilation of buildings (section 5.1):

- Ventilation rates, air movements and air quality can be affected by the building design, ventilation rates normally range from 2 to 200 air changes per hour
- Ventilation is one process by which bioaerosols are cleared from the air – sedimentation, impaction and electrostatic precipitation also play a role
- Ventilation rates control the emission of airborne pollutants from the building and the system design has a major effect on the environmental impact of the building
- Natural and mechanical ventilation systems can be used and there are recommended rates for different animals and different seasons. Total and respirable microorganism concentrations did not vary between naturally and mechanically ventilated pig finishing buildings
- There is little agreement about the influence of ventilation on dust concentrations – there may be a relationship between increased air flow and reduced dust particles but it is not strong. The settling out of dust particles on different surfaces is more important than ventilation rate

Seasonal effects on ventilation rates of livestock buildings include (section 5.1.1):

- Airborne dust and microbial concentrations increase as outside temperature decreases – although this relationship is not found if an internal heating system is used in pig buildings
- For poultry – the dust concentration in summer was half that found in winter in broiler houses even though the internal temperature was relatively stable – possibly due to increased ventilation in summer

The type of feed (wet or dry) and the way the animals are fed can impact on bioaerosol emissions but again the evidence is not always clear cut (section 5.2.1):

- In one study dry feed is noted as a major contributor to airborne dust levels in pig buildings whilst another stated that the type of feed had little impact on the daily average dust concentrations and the pigs themselves were major contributors

- Dust concentrations do increase during feeding but adding oil/fat to the feed may decrease the amount of dust in pig buildings
- Animal feed may act as a reservoir for fungi such as *Aspergillus flavus* and another study was able to distinguish moulds in side the building as different from those outside
- Specific feeding method: floor fed or trough feeding, restricted or freely available, indirectly affects dust concentrations – mainly due to how the activity of the pigs changes. One study found that higher dust concentrations were found during restricted feeding but another found the opposite

Litter/bedding types used in raising pigs in particular has changed in recent years. In the past most pigs were kept on slatted floors over an open pit to collect the waste but recently more animals are being kept on an enclosed compost bed of peat or sawdust. Stocking densities are lower and workers are exposed to lower levels of ammonia etc. but the compost must be turned regularly (section 5.2.2):

- Buildings using compost systems had airbourne microorganism concentrations 10-1000 times higher during turning of the compost when compared to traditional slatted floors. Fungal concentrations, especially those responsible for Farmer's lung disease were particularly high
- Greater concentrations of airbourne bacteria and respirable endotoxins are found if there is bedding. There was also a relationship between endotoxin concentration and humidity

For poultry the bedding used depends on whether they are laying hens or broilers. Laying hens are often kept in cages with no litter or on percheries with some litter. Broilers can have deep litter or be kept on netting over concrete floors.

- Floor litter is the main source of airbourne fungi in deep litter systems and the older the litter the higher the respirable dust concentration
- Deep litter systems have significantly higher respirable dust concentrations when compared with plastic netting systems

The way animal wastes are managed can also impact in bioaerosol emissions but again the literature is not that extensive (section 5.2.3):

- For pigs there is a difference between a system using a deep pit below a slatted floor as opposed to a pull-plug shallow pit with outdoor lagoon where the wastes are regularly removed to the outdoor lagoon – dust concentrations were consistently higher in the system using a deep pit
- For poultry (laying hens) there is a difference between cages with openings where the waste fell through to a lower level which was emptied every two weeks and a second system where waste fell onto a conveyor belt and was removed daily. Although dust levels were similar for both systems, bioaerosol emissions did vary – airbourne yeast were only found with the pit system and *E coli* counts were much higher for the conveyor belt system

There is a relatively extensive literature on occupational exposure of working in intensive agriculture activities and it is accepted that working in intensive pig and poultry farming can adversely impact human health (section 6). Respiratory symptoms (bronchitis, eye, nasal & throat irritation, reduced lung function, wheezing, chest tightness, cough etc.) are most common but asthmatic and allergenic responses also occur. Most symptoms are exhibited quickly after exposure (symptoms can occur

within 30 minutes of going into the livestock building but normally occur two hours or more after)

Causal agents investigated have included dust, ammonia and endotoxins and health effects are via inhalation of these airborne particles. Asthmatic and allergenic health effects can have many causal factors that includes exposure to microorganisms but also includes exposure to animal fur, feathers or hair, urine and grain dusts.

There is evidence of a dose response relationship between lung function decline and level of exposure to dusts, endotoxins and ammonia in some studies but not all. Symptoms experienced varied but for example 50 per cent reported acute bronchial, eye, nose and throat symptoms.

Although there is evidence to show that worker health can be impacted by intensive farming there is also variation in the type of activities they do. Tasks associated with pigs can be divided into about nine separate things with most time being spent mucking out pens, feeding and moving pigs. All these activities are known to be associated with high levels of dust and bioaerosol emissions. No work has been done on the bioaerosol production rates for defined tasks in pig production.

A similar picture is found for poultry growers with range of tasks such as feeding and watering. Poultry growers spend less time in the buildings than the poultry catchers and shacklers who spend most of the time in the buildings – levels of exposure to bioaerosols obviously varies widely. Some work has been done on chicken catchers, for example:

- highest dust levels were found when hens were put in to and older hens removed from the cages
- highest endotoxin levels were found when layer hens were put in to cages
- crews working at night had lower levels of exposure than those working during the day
- More than 85% of catchers had more than one acute symptom
- The method of catching affects level of exposure to microorganism and endotoxins – the 'draw method' results in higher exposure than the 'truck' method
- Bacterial concentrations are highest during shacking operations, levels of dust and endotoxin can be unacceptable

The way the birds are kept can have an affect on the levels of bioaerosols that workers are exposed to but the differences in health effects are not clear:

- In one study greater health effects were found with free-roaming birds but another showed greater effects with caged birds
- We know from other studies that higher concentrations of dust, microorganisms and endotoxin are associated with uncaged layer hens rather than caged birds

As awareness of the health impacts of intensive farming has improved so a range of control strategies have been developed (section 7). There are advantages and disadvantages of all the control strategies investigated. There is no one strategy that is always better than the others. Each control strategy is more effective in certain situations than others and all need to be assessed on a site-specific basis.

Table 9.1 Control strategies for bioaerosol emissions from intensive agriculture activities

Control strategy	Advantages	Disadvantages	Other comments
Vacuum cleaning – feed passages & pens	Good at reducing dust concentrations	<ul style="list-style-type: none"> • Expensive for large amounts of dust • Removal of surface dust is likely to increase airborne dust concentrations 	Cyclones would be more effective at cleaning the air but have high energy consumption and are not so effective for small particles
Electrostatic scrubbers	Electrostatic space charge system (ESCS) has been more successful with a significant reduction in total bacteria in egg hatching cabinets & a reduction in Gram-negative bacteria in broiler breeding rooms	<ul style="list-style-type: none"> • Negative ionisation in pig houses has limited effectiveness • Not suitable for areas with high dust levels such as around caged laying hens 	
Spraying with water/oil	<ul style="list-style-type: none"> • Fogging – increases dust particle volume (aggregate of dust & water droplets) • Showering - prevents settled dust becoming airborne at times of high animal activity such as weighing pigs or catching poultry • Mixture of canola oil and water can reduce inhalable and respirable dust concentrations, relatively cheap, easy to use, it also reduces acute health effects in workers 	<ul style="list-style-type: none"> • Fogging – expensive, only works for a short time (needs to be done 6-7 times per day) uses too much water/energy • Fogging - High moisture content could lead to increased microorganism concentrations 	
Filters & biofilters	<ul style="list-style-type: none"> • Usually consist of an internal particulate air filter, some can absorb odour, many different types of filtration media • Can be very effective in reducing microorganism concentration in pig and poultry buildings • Biofilters can significantly reduce the number of particles emitted from pig buildings • Airborne endotoxin and microbial volatile organic compounds are reduced by 90 per cent by all tested biofilters 	<ul style="list-style-type: none"> • There is a balance between filtration costs and the amount of dust removed • Differences in effectiveness of filter materials – e.g. biochips and compost are poor at removing cultivable and total bacteria. 	
Personal Protective Equipment	<ul style="list-style-type: none"> • Use of disposable masks does reduce exposure & measures are often cheap • Use of disposable mask - N-95 particle respirator - nearly eliminated all acute respiratory symptoms 	<ul style="list-style-type: none"> • Only of use in reducing impacts on occupational health 	Not widely used in the intensive farming sector - for occupational health, education on use of PPE is required

One of the most important factors to consider when regulating intensive agriculture activities is the potential impact on the wider environment (section 8). There is ample evidence that pig and poultry buildings do emit bioaerosols but some of the research is contradictory. We know what is likely to be contained in those bioaerosols and what can influence that composition (housing conditions etc.). What there is less evidence for is how those bioaerosols behave once they have been released from the livestock building, and in particular what distance they are likely to travel.

Factors that can influence bioaerosol emissions from livestock buildings include:

- Animal – type and growth stage – dust emission rates are generally greater for laying hens as opposed to broilers and for pigs being fattened rather than sows or weaners. Overall the highest emission rates for total microorganisms, fungi and endotoxins are from broiler houses (more than 100 fold higher than other emission rates)
- Building type – a critical factor is ventilation rate and whether this is natural or mechanical ventilation. *Staphylococcus* has been found in one study at 333m from a naturally ventilated poultry house but 477m from a mechanically ventilated building
- Bioaerosol concentration & distances travelled – e.g. one researcher found that airbourne bacteria concentration is highest 150-250m from livestock buildings. Another found that bioaerosol concentrations were 'markedly higher than background levels 200m away from the site with a dispersal range for total bacteria and staphylococcus of 420m.
- Seasonal effects – inhalable dust emission rates are higher in summer than winter but this is not reflected in respirable dust rates from the same facilities – respirable dust generation is possibly independent of season. Bioaerosol concentrations are affected by season - concentrations of airbourne bacteria from swine buildings are higher in winter than in spring, 100m from the building
- Local environmental conditions e.g. trees, other buildings – can have considerable influence over the airbourne distribution of bioaerosol but is difficult to predict and investigate
- Wind direction – the evidence is not clear cut e.g. researchers found that fungi and endotoxin concentrations were not elevated downwind of livestock buildings (compared to upwind) but total bacteria was (and in particular staphylococcus). This held for pig and poultry buildings. In general microbial concentrations downwind of livestock buildings are low and much lower than concentration inside the buildings but they are still above background levels.

9.2 Conclusions

The Environment Agency now has a responsibility under the IPPC regime to regulate larger intensive pig and poultry agricultural activities. A key part of that is managing potential exposure of the public (and especially people living close to intensive farming activities) to bioaerosol emissions.

The overall objective of this literature review was to try and move forward in answering the question:

- Am I at risk of ill health from environmental exposure to bioaerosols from intensive agricultural activities?

To be able to do this we need to have an understanding what we mean by 'bioaerosol' and in particular what is commonly found in bioaerosol emissions from intensive agricultural activities such as pig and poultry farming. Bioaerosols are particles of biological origin suspended in air and consist of (amongst other things) bacteria, fungi and bacterial endotoxins. In the context of pig and poultry farming there are three main sources of these type of bioaerosol components: animals, feed and bedding/excreta. Certain bacteria and fungi are more commonly found than others but some are common to both pig and poultry farming (bacteria – *Bacillus*, *Staphylococcus*, *Streptococcus*, fungi – *Scopulariopsis*, *Cladosporia*, *Mucor*). An understanding of what is typical is useful when trying assess the impact of bioaerosols on human health.

There are also a variety of sampling and analytical techniques to detect and quantify bioaerosol concentrations in air. No one technique is better than the others and all have to be assessed on a site-specific basis but techniques fall into three broad categories: impactors, impingers and filtration.

This review has identified several key factors that can impact on bioaerosol emissions *within* and *from* intensive livestock buildings and in particular pig and poultry farming. There are a range of factors that can be considered when assessing bioaerosol emissions in terms of potential adverse health effects from exposure to intensive agriculture activities which were summarised in section 8. Table 9.2 shows the main key factors and how they may impact on bioaerosol emissions, any differences between pig and poultry emission rates and any significant points which are worth highlighting. Further detail on each factor can be found in the relevant section of this report.

Although there is evidence to show the potential of bioaerosol emissions from intensive agriculture to raise ambient bioaerosol levels, the extent of this contribution to the overall atmospheric bioaerosol burden has not yet been defined. It is clear that emissions *may* increase the concentrations of bioaerosols inhaled by those living near to such activities. Currently there is insufficient evidence to fully assess the potential for this type of exposure, to increase the risk of adverse health effects (such as respiratory ill health).

Further information is required on which parts of the production processes for intensive pig and poultry activities make the greatest contribution to total bioaerosol emissions. This would help to identify the most appropriate control strategies in terms of occupational health and for the local population. We also need to be confident that any detected microorganisms and endotoxins do actually come from the livestock buildings themselves and not from the wider environment.

The way bioaerosols behave once in the wider environment in terms of distribution and dispersion also needs further work, as does the role of the weather (wind velocity, humidity and temperature) and obstacles such as buildings. Critically important to the

assessment of bioaerosol emissions from intensive agriculture and potential adverse effects in those living nearby are the correlations between bioaerosol concentration, particulate size and distance travelled. These relationships need to be investigated and fully characterised.

Finally, however, assessing whether there are potential adverse health effects from exposure to intensive agriculture activities must remain for the time being, a site-specific assessment. All such assessments must be risk-based to support robust, transparent and most importantly informed decision-making, whether potential risks are identified or not.

Table 9.2 Key factors important to bioaerosol¹ emissions from intensive pig and poultry farming

Factor	Impact on bioaerosol¹ emission	Specific pig or poultry effects	Key points
<i>Growth stage</i>	Age of the animals & how they are kept can affect their activity levels, the type of building they are raised in, how they are fed etc.	<ul style="list-style-type: none"> • Dependant on age (& weight) animals are housed differently • Pigs – include sows, weaners, fatteners • Poultry – include layers (caged or not) broilers, hatcheries 	Apart from whether the animals are pigs or poultry the growth stage dictates most other factors in some way e.g. type of bacteria & fungi making up the bioaerosol varies as poultry get older
<i>Building type</i>	<ul style="list-style-type: none"> • Directly linked to growth stage – intensive livestock buildings are not usually general purpose • Dust is usually mostly grain particles & dried faecal matter 	<ul style="list-style-type: none"> • Pigs - some studies found higher <i>total dust</i> levels in nursery/farrowing buildings and others found higher levels in finishing building • <i>Respirable dust</i> concentrations are higher in nursery/farrowing buildings • Laying hens - uncaged birds have much higher inhalable dust concentrations, caged birds have higher levels of endotoxins (3x more than pig buildings) • Broilers have high concentrations of inhalable & respirable dust, microorganisms and endotoxins and concentrations increase with bird age & weight 	<ul style="list-style-type: none"> • Bioaerosol emissions are higher from some types of building – linked to other indirect factors such as activity levels, feed, waste management etc • The evidence is not always clear, some studies have contradictory findings
<i>Animal activity</i>	<ul style="list-style-type: none"> • Directly linked to growth stage and in particular stocking density • More animal movement – higher the bioaerosol emission rate • Certain tasks have higher emission rates 	<ul style="list-style-type: none"> • Pigs – weighing & feeding produces high levels bioaerosols. Levels are higher during the day • Poultry – catching, shackling, dressing all produce very high levels of bioaerosols 	The increased activity of the animal, whether due to housing condition (free versus caged), time of day (daytime versus night), their stage of growth (farrow versus fattening) or their handling, corresponds to raised bioaerosol levels.
<i>Stocking density</i>	Higher the stocking density – higher the bioaerosol emission rate	Growth stage is critical as dictates type of building – e.g. in pigs nursery buildings produce more dust as animals are more active & easily disturbed	
<i>Ventilation</i>	<ul style="list-style-type: none"> • Natural or mechanical - ventilation rates normally range from 2 to 200 air changes per hour • Bioaerosol concentrations tend to be lower in summer <i>inside</i> buildings than in winter 	<ul style="list-style-type: none"> • Total & respirable microorganism concentrations did not vary between naturally & mechanically ventilated pig finishing buildings • For poultry – the dust concentration in summer was half that found in winter in broiler houses even though the internal 	<ul style="list-style-type: none"> • Ventilation rates control the emission of airbourne pollutants from the building and the system design has a major effect on the environmental impact of the building • Evidence not that clear yet, needs further work

Factor	Impact on bioaerosol ¹ emission	Specific pig or poultry effects	Key points
<i>Feeding method</i>	<ul style="list-style-type: none"> Type of feed – wet or dry important, freely available or restricted Distribution of dry feed & feeding – high concentrations bioaerosols produced Animal feed may act as a reservoir for fungi 	temperature was relatively stable	Evidence can be contradictory – requires further work
<i>Litter/bedding</i>	<ul style="list-style-type: none"> Bedding can be a source of bioaerosols and dust e.g. fungi Waste management system - dry faecal matter has been linked to raised bioaerosol levels 	<ul style="list-style-type: none"> Pigs – traditional slatted floor with waste pit or compost system. Compost systems had airbourne microorganism concentrations 10-1000 times higher during turning of the compost when compared to traditional slatted floors Poultry – floor litter is main source of airbourne fungi, older the litter the higher the respirable dust concentration 	The type of bedding/litter is important but how regularly it is removed could be more important
<i>Emissions to wider environment</i>	<p>All previous factors have an impact on bioaerosol distribution – key aspect is how is distance travelled from source affected</p> <ul style="list-style-type: none"> Bacterial distribution affected by ventilation type – travel further with mechanical ventilation Elevated levels found up to 500m from site but highest at around 150-250m 	<ul style="list-style-type: none"> Highest emission rates for total microorganisms, fungi and endotoxins are from broiler houses 	Much of the literature is around bioaerosol concentrations <i>within</i> buildings and the implication for occupational exposure – there are differences when looking at fugitive emissions
<i>Local landscape</i>	Trees, walls, other buildings – all have an effect on the distribution of bioaerosols	Although buildings differ probably has more to do with how buildings are arranged – difficult to predict and estimate	Requires further work
<i>Wind direction</i>	Differences upwind compared to downwind of pig/poultry activities in bacterial, fungal & endotoxin concentrations	<ul style="list-style-type: none"> Fungi & endotoxin concentrations not elevated downwind (compared to upwind) but total bacteria was (in particular staphylococcus) Microbial concentrations downwind of livestock buildings are low and much lower than concentration inside the buildings but still above background levels 	Requires further work
<i>Seasonal effects (temperature, humidity)</i>	Inhalable dust emission rates are higher in summer than winter but not respirable dust rates	Concentrations of airbourne bacteria from pig buildings are higher in winter than in spring, 100m from the building	Relationships not entirely clear – requires further work

¹ Bioaerosol includes dust, microorganisms and endotoxin

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Appendix 1 – Avian influenza and intensive farming

Introduction

Avian influenza (AI) is an infectious disease of birds that, on occasion, may infect other animals and humans. It is caused by viruses of the Influenza A genus, which can exist in very high numbers within the flesh, droppings and respiratory secretions of infected birds and other animals. The AI virus can also be released into the environment via the fluids from decomposing dead birds, where it can persist outside of a host and remain infectious for long periods of time. Irving *et al.* (2006) suggested that survival of the AI virus in the environment is promoted by low temperature, neutral pH, high levels of moisture and high levels of organic matter. However, there is very little peer-reviewed data on the survival of the AI virus in the environment. Stallknecht *et al.* (1990a, b) have examined the half lives of some AI viruses in ground water and surface water. Lu *et al.* (2003) have reported that the AI virus can survive in liquid chicken manure for more than 105 days at winter temperatures.

The viruses of the Influenza A genus are classified into subtypes based on antigenic (immune response) differences between their two surface glycoproteins: haemagglutinin (HA) and neuraminidase (NA) (Swayne *et al.*, 2003). Sixteen HA subtypes (H1–H16) and nine NA subtypes (N1–N9) have been identified for influenza A viruses (Kawaoka *et al.* 1990; Rohm *et al.* 1996). The natural reservoir for AI viruses is aquatic birds (also known as wild fowl). The gene pool of influenza viruses in aquatic birds is largely benign, but can evolve rapidly after transfer to domestic avian and mammalian species.

Of the 16 HA subtypes, only two – H5 and H7 – can evolve into high pathogenic avian influenza (HPAI), but both are of great concern to agricultural and animal health authorities, including the World Organisation for Animal Health (Webster and Hulse 2004; Kwon *et al.* 2005). AI viruses of the H5 and H7 subtype have only been isolated from avian species and humans (Shortridge *et al.* 1998; Bender *et al.* 1999). Most H5 and H7 AI viruses from wild aquatic birds and domestic ducks are of low pathogenicity (Hinshaw *et al.* 1980). However, in poultry such as chickens and turkeys, some H5 and H7 AI viruses have caused severe systemic disease with high mortality and are classified as HPAI. The most well known of the HPAI viruses is H5N1, which has a host range that includes poultry, ducks, geese, cats, mice, rats, ferrets, pigs, dogs, cattle horses and humans. In poultry, flock mortality can be close to 100 per cent, with an average infection to death period of around three days (Irving *et al.* 2006)

Background history of H5N1

The H5N1 virus was first detected in Guangdong Province, China, in 1996, when it killed some geese. It received little attention until it spread through live poultry markets in Hong Kong to humans in May 1997, killing six of 18 infected people. The culling of all poultry in Hong Kong ended the first wave of H5N1, but the virus continued to circulate among apparently healthy ducks in the coastal provinces of China. From 1997 to May 2005, the H5N1 viruses were largely confined to southeast Asia, but following the infection of wild birds with H5N1 virus at Qinghai Lake, China, the virus rapidly spread

westwards. The death of swans and geese marked H5N1's spread into Europe, India and Africa. One of the most recent outbreaks of H5N1 virus was confirmed in poultry in Turkey in mid-October 2005 and in humans in January 2006.

As of March 2007, 277 cases of H5N1 influenza have occurred in humans, with 167 deaths (WHO website 2007). Since 1997, over 230 million poultry and ducks worldwide have been killed directly by H5N1 or been culled in efforts to control the spread of the disease (Webster and Govorkova 2006). In February 2007 in the UK, intensively reared turkeys became infected with H5N1 virus. All 159,000 birds were slaughtered within 48 hours of confirmation of the virus' identity. Surveillance zones were set up centred upon the farm, however no H5N1 was identified off-farm in either wild or domesticated birds. The slaughtered birds carcasses were incinerated off-site. The litter in each shed on-site was piled up, sprayed with disinfectant and left for 42 days prior to incineration. Worker health surveillance was undertaken, no evidence of ill-health due to H5N1 virus was noted.

Lessons learnt following outbreaks of avian influenza in intensive poultry farms

The spread of avian influenza

HPAI, and in particular H5N1, has infected avian and mammalian hosts over a wide geographic area, encompassing Asia, Europe and Africa, in a relatively short period of time. Wild aquatic birds have been described as the natural reservoir of AI viruses and these birds are known to be capable of flying whilst infectious. It seems that HPAI viruses, like H5N1, that are highly pathogenic to domestic poultry are non-pathogenic to wild birds, which may well be infected and excreting the virus without showing any adverse effects (Sturm-Ramirez *et al.* 2005). There has been speculation as to the role of wildfowl, including ducks, in the spread of the virus to poultry.

Campitelli *et al.* (2004) reported the introduction of H7N3 virus from wild ducks into intensively-reared domestic poultry in Italy. These researchers compared the virus isolated from wild ducks in 2001 with that found circulating in intensively-reared turkeys from the same area in 2002–03. They found that the wild and domestic strains of AI virus were closely related at both the phenotypic and genetic level. The only major difference that they noted was a deletion in the stalk region of the NA molecule in the domestic virus. Campitelli *et al.* (2004) reported that their findings 'indicate that turkey H7N3 virus were derived "in total" from avian influenza strains circulating in wild fowl one year earlier'.

Sturm-Ramirez *et al.* (2005) examined the infectivity of 23 avian and human isolates of H5N1, derived from outbreaks in southeast Asia, on uninfected mallard ducks. Interestingly, these researchers found that the virus isolates exhibited differing pathogenic potentials in ducks, ranging from the complete absence of clinical disease to severe neurological dysfunction and death.

McQuiston *et al.* (2005) evaluated the spread of low pathogenicity H7N2 AI virus during an outbreak among commercial poultry farms in western Virginia in 2002. The results suggested that an important factor contributing to the rapid early spread of AI virus infection among commercial poultry farms was the method of disposing of dead birds, which involved rendering away from the farm. On the five farms initially infected in the outbreak, a common truck was used for the daily transport of the dead birds to a single rendering plant. McQuiston *et al.* (2005) suggested that the use of a common truck may have assisted the spread of the virus.

The use of a single rendering plant also served as a focal point of interaction for vehicles and personnel from private and commercial farms across the region. However, McQuiston *et al.* (2005) reported that the rendering plant was only used by 31 per cent of the infected farms, so they suggested that vehicle movement around the region may have had a role in the spread of the virus. Indeed, the number of feed truck visits to a farm in the two weeks prior to diagnosis did correlate to an increased risk of AI infection (McQuiston *et al.* 2005). The movement of family members and workers to and from the farm was also cited by McQuiston *et al.* (2005) as increasing the risk of AI infection, possibly due to increased vehicle traffic on the farm and the exposure of workers to infected birds whilst away from the farm.

Whilst investigating the 2003–04 epidemic of H5N1 in the Republic of Korea, Yoon *et al.* (2005) found that avian flu spread more rapidly on farms managed by employees instead of by a single family. Butler *et al.* (2006) have also reported that it is not only wild bird movements that contribute to the spread of H5N1, but that the movement of infected poultry and transport of infectious dead birds by humans also has an impact. These researchers suggested the virus can be spread in faecal matter on the gloves and boots of farm workers. Irving *et al.* (2006) suggested that evidence existed for the transport of H5N1 on the clothing of poultry workers and for the spread of other AI viruses on vehicles.

The investigation by Yoon *et al.* (2005) into the epidemic of H5N1 in Korea showed that the virus spread more quickly when large numbers of chicken houses were being used. These researchers also found that the disease spread more rapidly among layer chickens than among broilers. This is consistent with the results of a study by Thomas *et al.* (2005), who found an increased risk of the introduction of avian flu into layer hens compared with broilers. Thomas *et al.* (2005) examined data collected during the 2003 epidemic of avian flu in the Netherlands. They suggested that the increased risk to layer hens could be explained by the high number of contacts between different farms, especially via cardboard egg trays or the removal of eggs during the epidemic. This research group also reported that there were no significant differences between infected and uninfected farms with regard to housing type or the presence of cattle or pigs.

Strategies to reduce avian influenza in intensive poultry houses

Highly concentrated poultry farming, in conjunction with the live animal or ‘wet’ markets traditional to southeast Asia, provide optimum conditions for the genetic evolution of AI viruses. Strategies to prevent the development of new strains of AI and the emergence of pandemics include separating species, increasing biosecurity, developing new vaccine strategies and gaining a better understanding of the virus (Webster and Hulse 2004). Since wild birds are the source of all AI viruses, they must be excluded from poultry houses. Biosecurity measures such as screening intensive poultry houses for the presence of the virus, treating water and feed supplies and controlling access to farms are also crucial.

However, if these biosecurity measures fail to prevent the transmission of AI to the poultry and the virus becomes highly pathogenic then culling the birds is the most common method adopted for controlling the spread of the virus (Webster and Hulse 2004). In 2003, Japan and South Korea eradicated H5N1 in their countries through a strategy of quarantine and culling of poultry and by implementing improved biosecurity measures for poultry facilities. In Thailand, on the other hand, the same strategy resulted in only a temporary respite. After nearly a year with no H5N1 activity, new

cases in humans heralded the resurgence of H5N1 in domestic poultry in July 2006 (Webster and Govorkova 2006).

An alternative strategy adopted by China, Indonesia and Vietnam has been to vaccinate uninfected poultry, in conjunction with quarantining and culling infected birds. This approach has failed, however, and its critics blame the poultry vaccines, which they claim are largely of poor quality, do not provide sterilising immunity and promote antigenic drift. However, vaccines against H5N1 influenza virus have been successfully used since 2004 on all the poultry sold in Hong Kong, where no H5N1 virus has been isolated from fowl in live-bird markets despite extensive prospective surveillance. Webster and Govorkova (2006) suggested that the most important experiment in controlling H5N1 is being conducted in Vietnam. Following the adoption of a strategy to vaccinate all poultry with an inactivated, oil-emulsion H5N1 vaccine, there have been no additional cases to date in humans and no reported H5N1 infections in chickens. However, in September 2006, H5N1 was reported to have re-emerged in ducks and geese.

Impact of avian influenza viruses on poultry workers' health

The 1997 outbreak of H5N1 in Hong Kong was the first reported outbreak of AI to infect humans. There were 18 cases of human infection: a single case associated with an infected farm and 17 cases associated with live-bird markets. However, despite 20 per cent of the birds at the market being infected with H5N1, none of the human cases were poultry workers from the markets, which is the group expected to have the highest level of exposure to infected birds.

However, a study by Buxton-Bridges *et al.* (2002) confirmed that individuals with occupational exposure to domestic poultry on farms or at markets were at an increased risk of infection with the H5N1 virus. Buxton-Bridges *et al.* (2002) examined the H5 seroprevalence rate in blood samples from government workers involved in culling birds and poultry workers from the markets. They measured H5 seroprevalence rates of 3 per cent and 10 per cent for government and poultry workers, respectively. This suggests that a substantial number of mild and asymptomatic infections occurred in these occupationally-exposed populations. These researchers also reported a positive correlation between the number of poultry-related tasks undertaken and the percentage of anti-H5 antibodies that were detected. Based on these findings, they suggested that there was a greater exposure to H5N1 in the markets of Hong Kong than on the infected farms. They also proposed that the reason for the lower H5 seroprevalence rates in government workers was partially due to their wearing protective clothing and masks and partially due to their working on the farms as opposed to in the markets.

In 2003, there was a large outbreak of H7N7 avian influenza virus in commercial poultry farms in Holland (Enserink 2004; Koopmans *et al.* 2004; Thomas *et al.* 2005). The infection spread to 255 farms and the culling of all infected flocks led to the killing of around 31 million chickens. In the week following the outbreak, four independent reports suggested an increased incidence of health complaints, particularly conjunctivitis, in people involved in the control of the infected poultry. Koopmans *et al.* (2004) suggested that within a week of the first human case of H7N7 virus at least 1000 people were exposed to the virus and that, of those who developed symptoms, 59 per cent passed on the virus to household contacts.

Enserink (2004) reported the death of a single veterinarian during the outbreak. Koopmans *et al.* (2004) reported that, of 493 people with health complaints, 349 reported conjunctivitis, 90 had an influenza-like illness and 67 had other complaints. After examining blood samples, they found H7 antibodies in 78 (26.4 per cent) of the people with conjunctivitis, in five (9.4 per cent) of the people with influenza-like illness

and conjunctivitis and in two (5.4 per cent) of those with influenza-like symptoms only. However, Koopmans *et al.* (2004) did suggest a possible link between two infected workers involved in the outbreak at Gelderland, who lived in the North Brabant and Limburg areas of Holland, and subsequent outbreaks of H7N7 in these areas.

Appendix 2: Dust and microbial concentrations determined in swine confinement buildings

Reference	Collection	Breeding	Farrow	Nursery	Fattening/ finishing	Detection method
Donham <i>et al.</i> 1986	Total dust (mg/m ³)		3.15	5.2	15.3	Personal sampler-filtration
Donham <i>et al.</i> 1986	Total dust (mg/m ³)		4.1	10.8	9.0	Cascade impactor
Dutkiewicz <i>et al.</i> 1993	Total dust (mg/m ³)		6.81		5.18	Cascade impactor
Chang <i>et al.</i> 2001b	Total dust (mg/m ³)	0.15	0.23	0.34	0.28	Personal sampler-filtration
Takai <i>et al.</i> 1998* (England)	Inhalable dust (mg/m ³)	0.75	5.05		2.03	IOM filtration sampler
Takai <i>et al.</i> 1998* (Holland)	Inhalable dust (mg/m ³)	1.2	3.74		2.61	IOM filtration sampler
Takai <i>et al.</i> 1998* (Denmark)	Inhalable dust (mg/m ³)	3.49	3.37		1.65	IOM filtration sampler
Takai <i>et al.</i> 1998* (Germany)	Inhalable dust (mg/m ³)	1.39	2.8		2.31	IOM filtration sampler
Donham <i>et al.</i> 1986	Respirable dust (mg/m ³)		0.34	0.37	0.92	Personal sampler-filtration
Donham <i>et al.</i> 1986	Respirable dust (mg/m ³)		2.7	2.0	3.2	Cascade impactor
Takai <i>et al.</i> 1998* (England)	Respirable dust (mg/m ³)	0.13	0.43		0.22	Cyclone
Takai <i>et al.</i> 1998* (Holland)	Respirable dust (mg/m ³)	0.13	0.32		0.24	Cyclone
Takai <i>et al.</i> 1998* (Denmark)	Respirable dust (mg/m ³)	0.46	0.15		0.13	Cyclone
Takai <i>et al.</i> 1998* (Germany)	Respirable dust (mg/m ³)	0.12	0.29		0.18	Cyclone
Chang <i>et al.</i> 2001b	Respirable dust (mg/m ³)	0.12	0.08	0.13	0.24	Cyclone
Attwood <i>et al.</i> 1987	Total bacteria (cfu/m ³)		0.9x 10 ⁵		0.86 x 10 ⁵	Impinger
Cormier <i>et al.</i> 1990	Total bacteria (cfu/m ³)		1.5x 10 ⁵		4.9 x 10 ⁵	Andersen
Butera <i>et al.</i> 1991	Total bacteria (cfu/m ³)				4.62 x 10 ⁵	Andersen
Crook <i>et al.</i> 1991	Total bacteria (cfu/m ³)				2 x 10 ⁵ -6 x 10 ⁶	Impinger
Dutkiewicz <i>et al.</i> 1993	Total bacteria (cfu/m ³)		1.2x10 ⁶		10.2 x 10 ⁵	Filtration
Chang <i>et al.</i> 2001a	Total bacteria (cfu/m ³)	4.97 x 10 ⁵	1.8x10 ⁵	1.0x10 ⁵	7.56 x 10 ⁵	Impinger
Attwood <i>et al.</i> 1987	Gram -ve bacteria (cfu/m ³)		1.1x 10 ⁴		7.0 x 10 ³	Impinger
Cormier <i>et al.</i> 1990	Gram -ve bacteria (cfu/m ³)		80		140	Six stage Andersen
Dutkiewicz <i>et al.</i> 1993	Gram -ve bacteria (cfu/m ³)		2.1x 10 ⁴		2.5 x 10 ⁴	Filtration
Chang <i>et al.</i> 2001a	Gram -ve bacteria (cfu/m ³)	50	42	44	452	Andersen
Cormier <i>et al.</i> 1990	Total fungi (cfu/m ³)		150		190	Six stage Andersen
Fiser 1970	Total fungi (cfu/m ³)		2.5x 10 ⁵		3.4 x 10 ⁵	
Butera <i>et al.</i> 1991	Total fungi (cfu/m ³)				1.20 x 10 ³	Andersen
Crook <i>et al.</i> 1991	Total fungi (cfu/m ³)				2 x 10 ³	Impinger
Dutkiewicz <i>et al.</i> 1993	Total fungi (cfu/m ³)		4.1x 10 ³		1.65 x 10 ⁴	Filtration
Chang <i>et al.</i> 2001a	Total fungi (cfu/m ³)	3.57x 10 ³	3.0x 10 ³	2.3x 10 ³	2.49 x 10 ³	Andersen
Cormier <i>et al.</i> 1990	Total yeast (cfu/m ³)		0.5x 10 ⁵		0.4 x 10 ⁵	Six stage Andersen

Reference	Collection	Breeding	Farrow	Nursery	Fattening/ finishing	Detection method
Chang <i>et al.</i> 2001a	Yeast (% occurrence within fungal genus)		2.72	1.55	0.28	Andersen
Dutkiewicz <i>et al.</i> 1993	Thermophilic Actinomycete (cfu/m ³)		3.6x10 ³		0.8 x 10 ³	Filtration
Cormier <i>et al.</i> 1990	<i>Aspergillus sp.</i> (cfu/m ³)		0		0.25 x 10 ⁵	Six stage Andersen
Chang <i>et al.</i> 2001a	<i>Aspergillus flavus</i> (% of total fungi)			0.1	0.01	Andersen
Chang <i>et al.</i> 2001a	<i>Cladosporium sp.</i> (% of total fungi)		93.4	93.8	96.0	Andersen
Chang <i>et al.</i> 2001a	<i>Alternaria sp.</i> (% of total fungi)		0.2	1.09	0.82	Andersen
Chang <i>et al.</i> 2001a	<i>Penicillium sp.</i> (% of total fungi)		0.97	0.62	1.04	Andersen
Chang <i>et al.</i> 2001a	<i>Fusarium sp.</i> (% of total fungi)		0.4	0.51	0.72	Andersen
Dutkiewicz <i>et al.</i> 1993	Total endotoxin (µg/m ³)		15.21		53.13	Cascade impactor
Seedorf <i>et al.</i> 1998	Inhalable endotoxin (ng/m ³) day	114.6	186.5		135.1	Filtration
Seedorf <i>et al.</i> 1998	Inhalable endotoxin (ng/m ³) night	52.3	157.4		109.1	Filtration
Chang <i>et al.</i> 2001b	Inhalable endotoxin (EU/m ³)		82.1	298	136	Filtration
Seedorf <i>et al.</i> 1998	Respirable endotoxin (ng/m ³) day	8.3	17.7		13.0	Filtration
Seedorf <i>et al.</i> 1998	Respirable endotoxin (ng/m ³) night	7.4	18.9		11.4	Filtration
Chang <i>et al.</i> 2001b	Respirable endotoxin (EU/m ³)		48.6	20.9	129	Cyclone

Note: Takai *et al.* (1998) – sampling undertaken in four European countries.

Appendix 3: Dust and microbial concentrations determined in poultry houses

Reference	Collection	Broiler	Caged layer	Perched layer	Unspecified layer	Detection method
Clark <i>et al.</i> 1983	Total dust (mg/m ³)		2.34			Filtration
Takai <i>et al.</i> 1998* (England)	Inhalable dust (mg/m ³)	9.92	1.53	2.19		IOM filtration sampler
Takai <i>et al.</i> 1998* (Holland)	Inhalable dust (mg/m ³)	10.36	0.75	8.78		IOM filtration sampler
Takai <i>et al.</i> 1998* (Denmark)	Inhalable dust (mg/m ³)	3.83	1.64	4.86		IOM filtration sampler
Takai <i>et al.</i> 1998* (Germany)	Inhalable dust (mg/m ³)	4.49	0.97			IOM filtration sampler
Larsson <i>et al.</i> 1999	Inhalable dust (mg/m ³)		2.4	4.1		IOM filtration sampler
Takai <i>et al.</i> 1998* (England)	Respirable dust (mg/m ³)	1.14	0.21	0.35		Cyclone
Takai <i>et al.</i> 1998* (Holland)	Respirable dust (mg/m ³)	1.05	0.09	1.26		Cyclone
Takai <i>et al.</i> 1998* (Denmark)	Respirable dust (mg/m ³)	0.42	0.23	0.92		Cyclone
Takai <i>et al.</i> 1998* (Germany)	Respirable dust (mg/m ³)	0.63	0.03			Cyclone
Clark <i>et al.</i> 1983	Total bacteria (cfu/m ³)		4.2 x 10 ⁵			Andersen
Hinz <i>et al.</i> 1994	Total bacteria (cfu/m ³)	7.7 x 10 ⁶				
Clark <i>et al.</i> 1983	Gram –ve bacteria (cfu/m ³)		0.41 x 10 ⁵			Andersen
Hinz <i>et al.</i> 1994	Gram –ve bacteria (cfu/m ³)	810				
Clark <i>et al.</i> 1983	Total fungi (cfu/m ³)		500			Andersen
Clark <i>et al.</i> 1983	Endotoxin (µg/m ³)		0.31			Filtration
Larsson <i>et al.</i> 1999	Endotoxin (ng/m ³)		106	96		IOM filtration sampler
Hinz <i>et al.</i> 1994	Endotoxin (ng/m ³)	140				
Seedorf <i>et al.</i> 1998b (Day)	Inhalable endotoxin (ng/m ³)	785.7			860.4	
Seedorf <i>et al.</i> 1998b (Night)	Inhalable endotoxin (ng/m ³)	784.2			338.9	
Seedorf <i>et al.</i> 1998b (Day)	Respirable endotoxin (ng/m ³)	35.1			58.1	
Seedorf <i>et al.</i> 1998b (Night)	Respirable endotoxin (ng/m ³)	71.8			29.6	

Note: Takai *et al.* (1998) – sampling undertaken in four European countries.

Appendix 4: Summary of selection of studies investigating ill-health associated with working in animal confinement houses published between 1996 and 2006

Reference	Country	Study Population	Study Type	Outcomes	Exposures	Key findings
Eduard <i>et al.</i> 2001	Norway	106 farmers and spouses	Cross-sectional	Work related upper (WRURS) and lower respiratory symptoms (WRLRS)	Personal exposure to fungal spores, bacteria, endotoxins, $\beta(1-3)$ -glucans, fungal allergens and mites	PR for nose and eye symptoms 4–8 after exposure to $20\text{--}500 \times 10^3$ fungal spores/m ³ , PR for cough 4 after exposure to $500\text{--}17,000 \times 10^3$ fungal spores/m ³ , PR for nose symptoms 4–6 after exposure to $0.015\text{--}0.075\text{mg/m}^3$ silica
Melbostad <i>et al.</i> 2001	Norway	8482 farmers and spouses	Cross-sectional with nested exposure study	Task specific WRURS, WRLRS	Personal exposure to fungal spores, bacteria, endotoxins and ammonia during 12 different tasks (including tending of swine and poultry)	Task mean exposure levels positively correlated with task specific symptoms, prevalences for total dust, fungal spores and endotoxins but not bacteria and ammonia
Donham <i>et al.</i> 2000	US	257 poultry workers	Longitudinal study, cross-shift	WRRS and lung function (LF)	Personal exposure to dust (total and respirable), endotoxin (respirable and total) and ammonia	Significant dose response relationships between exposures and lung function decrements over a work shift. Exposure concentrations associated with significant LF decrements were 2.4mg/m^3 (total dust), 0.16mg/m^3 (respirable dust), 614EU/m^3 (endotoxin), 12ppm (ammonia)
Vogelzang <i>et al.</i> 2000	Netherlands	171 pig farmers working in swine confinement buildings (SCB)	Cohort study with three year follow-up	Bronchial responsiveness (BR)	Long term average personal exposure to inhalable dust, ammonia and endotoxin	Exposure to inhalable dust and ammonia, use of wood shavings as bedding and automated dry feeding significantly associated with increases in BR
Larsson <i>et al.</i> 2002	Sweden	16 SCB cleaners	Exposure study (three hours of exposure)	BR, inflammatory markers in nasal lavage fluid (NL) and peripheral blood (PB)	Personal exposure to inhalable and respirable dust	BR increased in all subjects following exposure, inflammatory markers in NL and PB increased following exposure, particularly in workers without a mask
Iverson <i>et al.</i> 2000	Denmark	181 pig and dairy farmers	Seven year follow-up study	BR, LF, WRRS	-	Accelerated decline in LF in pig farmers relative to dairy farmers; for non-smoking pig farmer, mean excess decline in FEV ₁ was 17ml/year

Reference	Country	Study Population	Study Type	Outcomes	Exposures	Key findings
Cormier <i>et al.</i> 2000	Canada	Eight volunteer SCB workers	Cross shift study, volunteers exposed for four hours at one week intervals to eight SCBs rated by cleanliness	LF, BR, inflammatory markers in NL and PB	Static measures of airborne dust, bacteria, endotoxin, moulds and ammonia	LF decreased and inflammatory markers in NL and PB increased after exposure, mean cross shift decline in forced expiratory volume in one second (FEV ₁) of 400ml, all SCBs similarly harmful
Donham <i>et al.</i> 2002	US	257 poultry production workers	Cross shift study	LF	Personal exposure to total and respirable dust, ammonia, endotoxin and CO ₂	Significant decline in LF over work shift, LF decline significantly associated with all environmental variables except ammonia, 43% of LF decline explained by synergy between ammonia and airborne dust
Radon <i>et al.</i> 2001	Denmark, Switzerland	76 pig and poultry farmers	Cross shift study	LF	Personal exposure to organic dust	Baseline LF results higher in pig than poultry farmers and associated with ventilation of animal houses, no cross shift differences observed
Radon <i>et al.</i> 2001	Denmark, Germany, Switzerland, Spain	6156 animal farmers	Cross-sectional study	WRRS	-	Pig farmers at highest risk of developing WRRS, significant dose response relationship observed between hours worked inside animal houses and symptoms for pig and poultry farmers
Kiryuchuk <i>et al.</i> 2003	Canada	303 poultry workers, 241 grain farmers, 206 non-farmers	Cross sectional study	WRRS, LF	-	Poultry workers reported highest prevalence of WRRS. Type of production method influenced prevalence of symptoms and LF, cage-based worse than floor-based
Kiryuchuk <i>et al.</i> 1998	Canada	42 SCB workers	Longitudinal study, follow-up 89–91 to 94–95, cross shift	LF	-	Mean cross shift change in FEV ₁ = 159.8ml, mean annual change = 53.9ml, cross shift change a significant predictor of annual rate change, endotoxin a significant predictor of annual rate change in FEV ₁
Jolie <i>et al.</i> 1998	US	Seven pig farms with high prevalence of respiratory disease in pigs (15 farmers), seven farms with low prevalence (16 farmers)	Cross-sectional study	WRRS, LF	Static measure of total dust, endotoxin and peptidoglycan	More farmers in high pig diseased farms reported chest tightness, mid-expiratory flow (MEF); % of predicted significantly lower in high pig diseased farms
Jolie <i>et al.</i> 1998	US	153 vet students	Exposure study	RS	-	RS (including cough, nasal and throat irritation)

Reference	Country	Study Population	Study Type	Outcomes	Exposures	Key findings
Zhang <i>et al.</i> 1998	Canada	visiting commercial swine farms 20 healthy volunteers, non-farmers	Exposure study in SCB, including treatment (with reduced exposure) and control building	BR, LF, white blood count (WBC)	Treatment room treated with canola oil to reduce levels of dust, endotoxin, ammonia and hydrogen sulphide. Control room (no intervention). Dust levels reduced by 93%, endotoxin by 89%, ammonia by 30%, hydrogen sulphide by 27%	reported by 91%, symptoms mostly developed on same day and resolved within three days from visit Shift changes in FEV ₁ and WBC significant in both treatment and control rooms, no significant difference between rooms
Von Essen <i>et al.</i> 1998	US	24 SCB workers, 14 controls	Cross-sectional	WRRS, LF, exhaled NO, induced sputum	-	Increased reporting of wheeze, cough and sinusitis, elevation of macrophages in induced sputum samples and small elevation of exhaled NO in SCB relative to control workers
Vogelzang <i>et al.</i> 1999	Netherlands	239 pig farmers, 311 rural controls	Cross-sectional study	WRRS	-	Pig farmers reported an elevated prevalence of symptoms of chronic bronchitis but not asthma and other allergies
Melbostad <i>et al.</i> 1997	Norway	10,792 farmers and spouses	Cohort study followed between 89 and 91	Symptoms of chronic bronchitis (CB)	-	Factors significantly associated with reporting of CB were fulltime farming, poultry, swine dairy and horse farming
Mackiewicz 1998	Poland	53 SCB workers	Cross-sectional study	WRRS, LF	Total concentrations of microorganisms	WRRS reported by 59% of workers
Reynolds <i>et al.</i> 1996	US	207 swine production workers	Cohort study with two year follow-up, cross shift	LF	Personal measurements of total and respirable dust, total and respirable endotoxin and ammonia	2% mean cross shift decrease in FEV ₁ , significantly correlated with total dust, total and respirable endotoxin and ammonia. Correlation of dust with FEV ₁ changes in workers with >6 years of exposure and >10 years of exposure, suggests that dust is an important factor in chronic disease. Correlation of endotoxin with FEV ₁ changes in workers with <6 years of exposure, suggests endotoxin may have more significance for sub-acute effects
Vogelzang <i>et al.</i> 1999	Netherlands	239 farmers, 311 controls	Cross-sectional	Organic dust toxic syndrome (ODTS)	-	Pig farmers suffered more ODTS than controls
Wang <i>et al.</i> 1997	Sweden	22 SCB workers	Exposure study (three hours of exposure), cross	NL and BAL to measure cytokine responses, BR	Personal exposure to inhalable dust, airborne endotoxin, 3-hydroxylated fatty acid,	Exposure to swine dust caused intense upper and lower airway inflammation characterised by elevated IL-1, IL-6 and TNF, also caused increased BR,

Reference	Country	Study Population	Study Type	Outcomes	Exposures	Key findings
Vogelzang <i>et al.</i> 1997	Netherlands	96 pig farmers with symptoms and 100 without	Cross-sectional shift	WRRS, LF, BR	Personal exposure to organic dust, endotoxin, ammonia muramic acid	significant association between IL-6 in BAL and endotoxin exposure BR associated with use of quaternary ammonia compounds as disinfectants (POR 6.7, 1.4–32.8), use of wood shavings as bedding (POR 13.3, 1.3–36.7), use of automated dry feeding (POR 2.8, 1.0–7.8), use of pellets as feed (POR 4.8, 1.1–21.1) and location of air exhaust via pit or roof in SCB (POR 2.7, 1.2–6.3). No association between BR and exposure to dust, endotoxin or ammonia
Simpson <i>et al.</i> 1998	UK	1032 workers exposed to organic dust from 9 different industries	Cross-sectional	WRURS, WRLRS, CB	Personal exposure to dust and endotoxin	Highest prevalence of symptoms found among poultry workers, a worker working in a SCB had symptoms consistent with byssinosis, increased current exposure to dust or endotoxin found to be predictive of U, L and CB symptoms and byssinosis. Relationship found between ODTS and current exposures
Sensithelvan <i>et al.</i> 1997	Canada	217 SCB workers, 218 grain workers, 179 non-farmers	Longitudinal study, follow up over four years	Annual rate of LF decline	-	SCB workers had largest annual rate of FEV ₁ decline, (excess annual decline 26.1ml) over non-farming controls
Zhiping <i>et al.</i> 1996	Sweden	38 SCB workers	Exposure study, cross shift (three hours of exposure)	Serum cytokine levels (markers of acute systemic respiratory effects), RS, LF, BR	Inhaled bacteria markers (peptidoglycan – measured from muramic acid, LPS – measured from 3-hydroxy fatty acid)	All exposure markers correlated significantly with levels of IL-6. LPS showed highest correlation. LPS also correlated with symptoms and BR

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