The Planning Inspectorate

Costs Decision

Inquiry opened on 17 December 2013
Site visit made on 20 December 2013

by Martin Whitehead LLB BSc(Hons) CEng MICE

an Inspector appointed by the Secretary of State for Communities and Local Government

Decision date: 15 January 2014

Costs application in relation to Appeal Ref: APP/K3415/A/13/2199283
Cleat Hill Farm, Syerscote Lane, Haunton, Tamworth, Staffordshire B79 9HB

- The application is made under the Town and Country Planning Act 1990, sections 78, 320 and Schedule 6, and the Local Government Act 1972, section 250(5).
- The application is made by Mr J Davison for a full award of costs against Lichfield District Council.
- The inquiry was in connection with an appeal against the refusal of planning permission for the formation of a new poultry unit and associated works.

Decision

1. The application for an award of costs is allowed in part in the terms set out below.

The submissions for Mr J Davison

2. The submissions were made in writing[1] and orally at the inquiry, which are summarised below.

3. The application for a full award of costs is made on 3 grounds. With regard to the unreasonable refusal, the Council has identified no authoritative guidance to support its odour and noise issues and the appeal decision that it has referred to late into the inquiry has been no use. It has failed to show clearly why the development should not be permitted.

4. The Council has conceded that the issue with flies and public health can be dealt with by condition. It has not shown that the dispersion modelling of odours is incorrect or inadequate and has acted unreasonably in rejecting it. The appellant has supported it by previous appeals and ADAS giving robust, objective evidence. Also, the Council has not given any objective measure why a maximum of 18 Heavy Goods Vehicle (HGV) movements in one week out of 7 is unacceptable.

5. The Council has been aware of previous appeal decisions and has not addressed these in its decision. It has acted unreasonably in pursuing the appeal on this basis having received the appellant's evidence. The Council should have asked the question as to whether the proposal would be able to operate successfully, having been granted an Environmental Permit. It has taken account of, and weighed heavily upon, objections that have had no

[1] Appeal Document 21

accurate analysis and no support from statutory tests or policies. As such, it has relied upon assertions and its witnesses have failed to withstand the scrutiny.

6. All the appellant's witnesses have been needed to give evidence at the inquiry, including the traffic evidence from Mr Tucker, who was not cross examined on it by the Council. This evidence was a necessary element of the noise and disturbance issue in order to justify the nature and extent of the resulting increase in HGVs. Also, he was questioned by objectors on his evidence in relation to the objections.

7. With regard to the Statement of Common Ground (SOCG), the Secretary of State's guidance requires matters that are agreed to be included. The Council did not agree common ground on the main issues, which were capable of agreement at the time.

8. The Council called witnesses to maintain its position but the evidence was not objective, rational or on a reasoned basis. It was based on assertions and the objective evidence of the appellant was left untroubled. This has not provided a means of escape from the Council's unreasonable refusal of planning permission which ought to have been granted in the first instance.

9. Should an award of costs not be considered appropriate on all the grounds, a partial award is sought on any or all of the following: traffic, odour, flies and the SOCG.

The response by Lichfield District Council

10. The response was made orally at the inquiry, which is summarised below.

11. With respect to Ground 1, the reasons for refusal are sufficient due to the non-compliance with the development plan not being outweighed by other considerations. The Council provided an evidential basis to support its decision. The matter of flies was a live issue from objectors that had to be considered by the Council. The Council has shown that the proposal is not acceptable having regard to the development plan and Framework. The Council has used the evidence of Ms Gannon to support its reasons for refusal on odour and noise which has clearly demonstrated why the development should not be permitted.

12. The Council's Statement of Case identifies in paragraphs 6.1 and 7.1 the noise and odour issues that would have a detrimental effect on amenity. With regard to HGV movements, it is not necessary to identify the times when this would be worst in the Statement of Case. Even though an Environmental Permit has been granted, the Council has shown that there still would be a detrimental impact as a result of odour.

13. The objections have raised multiple issues in relation to acceptability. The Council has considered the issues raised and not the volume of objections. It is entitled to make a decision on this basis when it is reasonably supported by evidence.

14. With regard to the objectivity and reliability of the Council's evidence, it called expert witnesses. Its witness regarding odours showed that the impact could not all be modelled but required an element of subjectivity. Little had been known about what would happen when cleaning sheds and this is not able to be

modelled. Ms Gannon gave her subjective judgement having previously dealt with these issues. There is also an element of subjectivity on the effect of noise and the Council's witnesses remained of the opinion that there would be an unacceptable impact.

15. In terms of Ground 2, the Council has indicated in its evidence that it does not consider that odour issues would be able to be dealt with by condition, as management practices would not be able to prevent an odour impact associated with the proposal. Also, it has shown that conditions would not be able to deal with the noise issue. The issue of flies has fallen away.

16. With respect to Ground 3, the failure to agree a SOCG has to be shown to have resulted in wasted or unnecessary expense. Not every agreed fact needs to be included in the SOCG. The matters regarding the reasons for refusal are dealt with in the proofs of evidence.

17. The evidence provided by Mr Tucker with regard to traffic has not been questioned and was not necessary as it did not go into the live issues. This has been an unnecessary expense at the inquiry and should not be included in any award of costs.

Reasons

18. Circular 03/2009 advises that, irrespective of the outcome of the appeal, costs may only be awarded against a party who has behaved unreasonably and thereby caused the party applying for costs to incur unnecessary or wasted expense in the appeal process.

19. Ground 1 of the application for costs is based on an unreasonable refusal of planning permission. In this regard, the Council has provided 2 reasons for refusal which are complete, precise, specific and relevant to the application and refer to relevant development plan policies, albeit that some of those policies have since been revoked. These are based on harm to amenity by virtue of the scale and nature of the development and proximity to nearby villages and the associated increase in HGV movements. They have been expanded upon in the Council's Statement of Case, which indicates that they are regarding the impact from odours, air quality, flies and noise from HGV movements associated with the stocking of poultry units and removing chickens for slaughter.

20. The Council has produced evidence in the form of proofs of evidence from two expert witnesses who have also appeared at the inquiry. They have referred to the development plan and other material considerations, including emerging policies, the National Planning Policy Framework, and odour and noise guidance. As such, they have substantiated the reasons for refusal. Whilst they have accepted at the inquiry that the risk to public health from flies would be capable of being adequately controlled, this does not detract from the other evidence provided in relation to odours and noise from HGVs.

21. The effects of odours and noise on the living conditions of local residents are matters of judgement. I am satisfied that the evidence provided by the Council's witnesses in relation to these matters has been realistic and specific regarding the consequences of the proposed development. Whilst I have not accepted the arguments put forward, I find that they are not solely based on vague, generalised or inaccurate assertions about the proposal's impact, but

refer to guidance and standards, highlighting where they could be deficient with respect to determining the actual impact.

22. The Council is not bound to accept the recommendations of its officers and should provide a clear and rational explanation why it rejects the advice from statutory consultees. In this case, the Environment Agency has not objected and has issued an Environmental Permit (EP). However, I am satisfied that the Council has produced relevant evidence on appeal to support the decision with respect to noise from HGVs and odours.

23. The Council has considered the views of local residents when determining the planning application and much of this opposition has been founded on valid planning reasons, including the impact of HGVs and odours. I find that in relation to these 2 matters, the Council has shown that it has made its own objective appraisal and provided substantial evidence.

24. Ground 2 of the application for costs is regarding the consideration of relevant planning conditions. The conditions that the Council's officers suggested in recommending approval of the application are similar to those given in the SOCG. In this respect, the Council had been referred to the planning conditions when it made its decision. Whilst I have accepted that the matters that are the subject of the reasons for refusal could be adequately addressed by planning conditions, the evidence submitted on appeal has provided plausible reasons why such conditions would not be effective. With respect to the matter of flies and public health, I find that this matter is capable of being dealt with by condition and such a condition had not been properly considered when refusing planning permission.

25. Ground 3 of the application for costs is as a result of a failure by the Council to agree factual matters in the Statement of Common Ground (SOCG). This is particularly relevant in terms of the spread of manure and the number of vehicle movements that would be generated by the proposal. The appellant has included facts in the draft SOCG related to these matters which the Council has removed prior to agreeing the Statement. This has meant that the appellant has called a witness to deal with traffic matters (Mr Tucker), who the Council did not question, and has included evidence regarding the spread of manure, which the Council accepted at the inquiry was not part of the grounds for refusal. It has resulted in more time being taken at the inquiry than would otherwise have been the case.

26. I do not accept that Mr Tucker should have been called to answer questions from objectors as they did not have any substantive evidence to contest the traffic flows and the other matters regarding traffic and highway safety had been agreed by the Council and statutory authorities. The attendance of Mr Tucker and the evidence that he gave at the inquiry would not have been necessary and could have been avoided had the Council agreed beforehand to the facts that have been commonly accepted by both parties. Also, had the impact from the spread of manure been agreed in the SOCG, it would have avoided the need to include this in the evidence provided by the witnesses and would have reduced inquiry time in examining this evidence.

27. For the reasons given, I find that the Council's reasons for refusal are not unreasonable. As such, the Council has not prevented or delayed development which should clearly be permitted, but the applicant has incurred unnecessary expense in providing additional evidence on appeal regarding the impact of fly

infestation, the storage and spread of manure, and traffic, other than its resulting noise. Therefore, I conclude that unreasonable behaviour resulting in unnecessary expense, as described in Circular 03/2009, has been demonstrated and that a partial award of costs is justified.

Costs Order

28. In exercise of the powers under section 250(5) of the Local Government Act 1972 and Schedule 6 of the Town and Country Planning Act 1990 as amended, and all other enabling powers in that behalf, IT IS HEREBY ORDERED that Lichfield District Council shall pay to Mr J Davison, the costs of the appeal proceedings described in the heading of this decision limited to those costs incurred in the preparation and presentation of evidence for the appeal regarding the impact of fly infestation, the storage and spread of manure and traffic provided by Mr Tucker.

29. The applicant is now invited to submit to Lichfield District Council, to whom a copy of this decision has been sent, details of those costs with a view to reaching agreement as to the amount. In the event that the parties cannot agree on the amount, a copy of the guidance note on how to apply for a detailed assessment by the Senior Courts Costs Office is enclosed.

M J Whitehead

INSPECTOR

General enquiries on this form should be made to:
Defra, Science Directorate, Management Support and Finance Team,
Telephone No. 020 7238 1612
E-mail: research.competitions@defra.gsi.gov.uk

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Project identification

1. Defra Project code: AC0104
2. Project title: Characterising poultry dust properties, assessing the human health implications, quantifying emission levels and assessing the potential for abatement
3. Contractor organisation(s): Royal Veterinary College; Centre for Ecology and Hydrology; Health and Safety Laboratory; ADAS
4. Total Defra project costs (agreed fixed price): £ 461,188
5. Project: start date ..... 01 August 2006
   end date ..... 31 January 2009

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so..... YES ☒ NO ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.
In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

This project aimed to characterise poultry dust, quantify emission levels, assess the potential of emission abatement techniques and the potential impact on human health. To date limited bioaerosol concentration and emission data is available. Current estimates of the UK National Atmospheric Emissions Inventory (NAEI) suggest that poultry husbandry accounts for 1,620 and 8,980 t yr^{-1} of $PM_{2.5}$ and PM_{10}, respectively. This corresponds to 2.0% and 5.9% of the total primary anthropogenic emissions.

During this study a total of eight poultry farms, broiler, caged layer, free range layer and two broiler farms fitted with abatement techniques, were visited twice (summer and winter). Dust concentrations were measured for the various size fractions and size distribution determined. The chemical composition of the dust was established from the material collected on the filter samples. The bio-aerosol composition of dust collected on filters was measured for samples collected inside the buildings as well as at 50, 100, 200 and 400 m from the building to establish the potential hazard to human health. This work provides one of the most extensive studies of poultry dust emissions to date. The main results are summarised below.

- Measured in-house concentrations and emission factors of $PM_{2.5}$ and PM_{10} were within the range of previous measurements, but the average was significantly lower than the average of former studies, especially for broilers. One recent study, however, reported even lower emission factors. This difference probably reflects changes in housing construction and management, bearing in mind that this study focussed on modern houses and is more representative of current and future conditions than for past emissions. Surprisingly high emission factors were found for housing emissions of free-range layers, for which literature data is very sparse. A likely reason is that the birds move over solid flooring from which particles are easy to re-suspend and ventilation rates are high.

- Using the emission factors derived here, overall UK emissions of PM from poultry are reduced by a factor of about 4 compared with the NAEI.

- As expected, emission factors were highly variable between farms, visits as well as day and light periods, most of which can be explained with the type of housing, changes in bird activity and differences in ventilation rates. In addition, the three instruments used to measure emission factors showed considerable variability. To increase the robustness of emission factors further, a larger number of farms would need to be investigated.

- The use of abatement systems in the UK was found to be limited to a small number of broiler farms.

The two abatement approaches indentified were: abatement using two baffles and water bath outside the fans (U-bend principle) and a StuffNix filtration system. These were found to remove 22% and 67% of the PM_{10}, respectively. However, these results should be generalised with caution as they are based on a small sample size.

- Ammonia emissions were also in the range of previous estimates, but average emission factors are 50% higher than those used to calculate the official UK emission estimates. It is expected that future attempts to reduce ammonia emissions from poultry husbandry are also likely to reduce PM emissions.
- The poultry installations were not found to be a significant source of sub-micron aerosol and related chemical components.
- Chemical analysis of the dust particles by aerosol mass spectrometry, EDX, ICP-MS and liquid ion chromatography revealed Al, As, Ba, Ca, Cu (light only), Cr, K, Mg, Mn, Na, Rb, Sm, Sr and Ti to be significant components of the poultry dust. First UK poultry emission estimates were derived for most of these elements, suggesting that the contributions to the UK anthropogenic emission inventory range between 0.1 and 4%, depending on the element.
- Bioaerosol concentrations were measured within the poultry houses, at the exhaust fans, as well as upwind and at several distances downwind and analysed for bacteria, fungi and endotoxin. While in-house concentrations are of potential concern to poultry workers, due to dilution and dispersion effects, concentrations approach background values at a distance of about 100 m downwind. Emission factors have been calculated. The bacterial and fungal composition was typical for agricultural areas and *E.coli* were only identified during one single farm visit.
- It has been suggested that particle filtering may indirectly abate ammonia emissions since some of the ammonia may condense onto the dust particles inside the poultry houses. This process (and thus the abatement potential for ammonia) was found to be negligible.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

Table of Contents

1 Introduction

Elevated concentrations in atmospheric dust have been associated with an increase in a range of human health problems, such as respiratory and cardiovascular disease. In Europe (and thus in the UK), exposure to inhalable dust (ID) is regulated by setting Air Quality Standards for the mass of particulate matter contained in particles < 10 μm aerodynamic diameter (PM_{10}) and in particles < 2.5 μm ($PM_{2.5}$), two metrics for which epidemiological associations have been reported. PM concentrations are composed of primary particles (from combustion sources and friction processes) and secondary particles, which are not emitted as particles, but formed by chemical reactions from pre-cursor gases such as ammonia, nitrogen oxides, sulphur dioxide and volatile organic compounds.

Agricultural activity contributes to the primary emission of dust with an absolute contribution that is thought to have remained largely constant over past years. One agricultural activity associated with dust emissions is the housing of livestock, and in particular poultry. The emitted poultry dust is a complex mixture of inert dust from soil, together with organic material derived from feed, litter, faecal material, dander (skin material), feather and micro-organisms. Factors affecting dust concentrations are type of bird, type of housing system, bedding materials, litter condition, air temperature, humidity, air flow rate, type and amount of feed and animal activity level (Rosentrater et al, 2004).

Some of the components of poultry dust have been associated with respiratory symptoms in exposed workers, including asthma and chronic bronchitis (Whyte, 1993). The micro-organisms, predominantly fungi and bacteria that may form part of poultry dust could cause respiratory allergies. Bacterial endotoxins, parts of the cell walls of some bacteria, can trigger 'flu-like symptoms if inhaled. As a whole, these biological components of airborne dust are referred to as 'bioaerosols'.

Dust concentrations were first recorded for human occupational health surveys (Whyte, 2003). Wathes *et al* (1998) and Takai *et al* (1998) have recorded aerial emission rates from different classes of housed poultry. Not only can dust be hazardous to health, it may also impair the performance of ventilation systems by accumulating on timers, thermostats, fan motors etc which can cause them to perform poorly or fail completely (Kim et al, 2005). As economies of scale have resulted in poultry houses and farm size becoming larger over time, the amount of dust produced as a point source has also increased.

Although making a moderate contribution to the national UK primary dust (PM_{10}) inventory overall, the contribution of animal housing to total primary emissions of PM_{10} is estimated to have grown from 2.8% in 1990 to 5.2% in 2000 (RAINS, 2005) and 8% in 2002 (Wathes *et al*, 2002), with the latest (2006) official UK estimate being 5.9%. Emissions from animal housing are thought to be dominated by poultry livestock operations, followed by pig husbandry. Kilmont and Amann [2002] estimate that the poultry sector is responsible for 57% of the PM_{10} and 50% of the $PM_{2.5}$ emissions from animal housing, while RAINS (2005) estimates contributions of 40% and between 35 and 45%, respectively. However, these estimates are based on a very sparse database of PM emission factor [*UNECE/EMEP*, 2007], and even less is known about the nature of the aerosol in terms of size-distribution, physical, chemical and biological characterisation. There is growing concern that dust from livestock buildings can cause exceedance of UK Air Quality Standards locally. In addition, the presence of bioaerosols in dust from livestock buildings poses a significant but to date largely unknown and unquantified risk to the human population in the vicinity (Wathes *et al*, 2002).

The main aim of this project was to characterise poultry dust (40% of agricultural dust emissions) in terms of its physical, chemical and microbiological properties through detailed measurements at six poultry production sites and to quantify emission factors for the improvement of national emission estimates. The identified properties enabled assessment of the human health implications of dust emissions using the measured exposure levels.

Abatement of dust emission is the obvious route to lower the human exposure levels. Only two dust abatement techniques were found to be used in the UK, StufNix filters and a "settling" chamber. Both were assessed on the basis of efficacy, practicality, and cost.

The objectives were as follows:

1) To further characterise the elements of fine dust (PM_{10}) emitted from poultry houses on the basis of its physical, chemical and microbiological properties
2) To assess the human health implications of dust emissions from poultry houses, particularly for those living in the vicinity of poultry production facilities
3) To identify dust emission abatement measures and assess their efficacy and cost
4) To assess the impact of effective dust abatement measures on other forms of pollution
5) To establish dust emission factors for poultry houses under traditional operation and with abatement measures

2 Potential dust abatement techniques

In the UK, farms operating with an Environmental Permit in 2008 are obliged to demonstrate some measure of dust management. Typical measures currently deployed are dilution in the atmosphere by using roof fans mounted in carefully designed chimneys that develop a high velocity exhaust, or dust capture either in dedicated drains or holding tanks, or into some form of biological filter such as a reed-bed or screen from side-wall fans and cowled roof fans.

For a dust abatement technique to be successful in a poultry building, it must not interfere with the primary roles of the ventilation system, either by restricting or altering air distribution, or by adversely affecting the condition of litter for floor reared birds (Tucker and Walker 1992). In the short term, they need to be sufficiently adaptable to be retro-fitted and operate in different production systems found within the poultry industry (Kim et al, 2005). In the longer term, for more effective operation, there will be opportunities for production systems to be designed around the abatement system.

In principle, dust can be controlled in terms of generation and emission, the latter either as it leaves the building or when it is airborne thereafter (Patterson and Adrizal 2005 and Rosentrater, 2003). Sedimentation and impaction can also be used within the building (Weeks and Butterworth).

2.1 Control of dust at source

Controlling dust at the source not only reduces emissions to the external environment, but it also helps to maintain a better house environment for both animals and humans (Tymczyna et al, 2007). Operating equipment suffers less impairment due to dust contamination. Methods of reducing dust at source include, for example, reviewing structure and composition of feed and bedding materials, use of non-litter systems, dust removal by spraying liquids, capture, ventilation, and cleaning.

2.1.1 Feed

One component of livestock dust is feed (Takai *et al*, 1998). The dust levels may be increased if the form of the feed is initially dusty, as with some non-pelleted feeds for laying hens. Broiler feed is less dusty as it is moulded into pellet form that contains a higher level of fat within the feed itself.

Some feed ingredients have been found to affect dust concentrations when used in high quantities within the poultry diet. Haler et al (2002) found that a high barley content elevated dust levels when compared with maize. Heber and Martin (1988) also found that wheat produced 5.8% higher dust levels than the equivalent diet made from maize. Maize, for agronomic and economic reasons, is not readily available in the UK compared with wheat and is not commonly used in UK poultry diets.

The equipment in which feed is administered can also increase the amount of airborne dust. Li *et al* (1993) found that dust increased by 150% when both meal and pellet feeds were administered by a "screw" auger system rather than by hand. Automatic feeders can generate dust when feed is being dropped into the troughs, especially if the feed is as a meal or if the pellets are badly formed. Feeders that "over administer" are also a cause of dust formation, for example in broiler housing (Aarnink et al 2007). The spilled feed is gradually crushed on the floor into smaller particles which become airborne due to bird activity.

2.1.2 Bedding

A second source of poultry related dust emissions is the resuspension of bedding material. Takai et al. (1998) and Ellen et al. (2000) found that dust emissions were four to five times higher from houses using bedding rather than cages with wire floors. However, many egg producers in the UK and throughout Europe are moving towards littered systems for poultry on the grounds of animal welfare. Various bedding materials are used, such as sawdust, flax, wheat, barley or rye straw paper, clay pellets, peat and wood shavings. Adding water to the bedding material reduced the dust concentration, but is not consistent with the requirement for a dry friable litter (Gustafssen and Von Wachenfelt, 2006). Spraying oil is an inexpensive and effective abatement method with up to 90% of airborne dust removed (Aarnink *et al*, 2007; Ikeguchi, 2002). However, this method mainly prevents particles on surfaces from becoming airborne again by making them too heavy, leaving a large deposit on building surfaces making cleaning more difficult and equally raises concerns regarding the quality of the litter.

Deep bedding systems as used in turkey and duck production have been shown to contribute less dust to the environment than shallow bedding systems (Aarnink and Ellen, 2007). Deep litter is thought to "sediment" the dust to the lower layers of the bedding where the increased humidity traps the dust particles and helps to bind it in place, reducing dust concentrations by approximately 50%. However, deep litter is not deemed suitable for broilers, as litter deeper than 5 cm resulted in a significantly ($P< 0.05$) higher prevalence of foot-pad dermatitis (Ekstrand *et al.*, 1997) in the flock. As bedding materials break down to a dry friable litter dust production increases. As the straw degenerates with time, fine straw particles become airborne and elevate house dust levels (Aarnink *et al* 2007). Even with "pre-packed, dust-extracted" bedding materials, dust levels will be low at first but will increase due to activity occurring in the litter.

In trials where relative humidity was increased to 75% with misting systems at lower ventilation rates in autumn and spring month's reductions in inhalable dust of approximately 13% and 22.5% were found (Ellen *et al*, 2000). Increasing relative humidity in littered floor systems might meet with resistance from the industry due to the potential of footpad dermatitis resulting from damp litter. However, the technique might be effective in the summer months.

2.1.3 Dust capture systems

Dry filters can be fitted to internal air recirculation units. Reducing dust in animal house air by filtration can be applied as a measure for improving the environment in pig keeping (Haberman *et al*, 2005). When used in flat-deck rooms with early-weaner pigs, an internal filter system reduced dust mass and bacterial colony-forming particle concentrations by between 50 and 60% (Carpenter and Fryer, 1990). However, these simple and effective techniques have not been fully utilised.

Electrostatic Space Charge Systems (ESCS) are devices that impart electric charges to dust particles. They then use either electromagnetic forces to push the particles out of the airstream into a collection tray, or to attract them to earthed surfaces. In laboratory studies, they have shown high efficiencies of up to 90% airborne dust removal at low operating costs (Rosentrater, 2003). Preliminary results of a study in a broiler production house during the cool months of November through to April indicated the ESCS reduced airborne dust by an average of 55% (Bailey *et al* 2003). However, although the construction is simple, operating costs are relatively low and airborne dust removal is significant, the electrostatic collectors still need development before they can be used to great effect within commercial poultry houses with large air change rates. Internal recirculation of air is currently being more widely used to improve heat distribution and thus save on heating costs, and could be modified to accept dry filters and thus improve dust control.

2.2 Control of airborne dust at point of emission

Dust particles that have not been trapped, re-settled or eliminated at source remain airborne within the building and are ultimately exhausted to atmosphere by the ventilation system. Since in many poultry houses air is exhausted from the fans, there is an opportunity to trap dust as air leaves from these specific locations.

Natural or artificial screens or wind-breaks (Jacobson *et al,* 2001 and Bottcher *et al,* 2000), intercept dust particles and/or redirect the exhaust air into the atmosphere for better dilution and dispersion. In one study, after three rows of trees the air speed was reduced and total dust levels reduced by approximately 50% (Hoff *et al* 1997). A parallel Defra funded project (AC0201) is currently investigating the efficacy of farm woodlands in abating UK ammonia emissions from different on-farm sources, and a similar study would be relevant for dust abatement.

Passive dry air-cleaning units in poultry houses are essentially filters that can accommodate large air changes. Air being drawn to the exhaust fans must pass through the filter wall placed in a plenum chamber and is subject to many direction changes within the body of the filter. The centrifugal force of air circulating in the many cavities of the filter separates the dust from the air flow, allowing it to fall into collection pockets that can be emptied. Filters do present a resistance to air flow, so fans must operate at higher pressure. However, whilst this may not be an issue in some classes of stock, the system must allow for high air volume and air speed necessary for heat stress relief in broilers. Commercial results suggest a 70% reduction in visible exhaust dust. Benefits are that filters can be "retro-fitted" to most existing houses. Several examples have recently been fitted to UK broiler farms.

Water air-cleaning units or "scrubbers" intercept dust as air passes through a water or chemical spray, often over a contact matrix, to remove up to 93% (Aarnink *et al* 2007) of the larger dust particles. Combining wet scrubbers with acid scrubbers (pH1.5) can also remove 99% of ammonia and some odour compounds. Frequently, additional stages, for instance biofilters, where air is passed through a bed of moist organic substrate such as heather, are added to further remove dust particles, ammonia (70%) and odours (Snell and Schwarz, 2003). The drawback of active wet air-cleaning units is the higher pressure drop over the system (150 Pa, 5 times more than standard systems) and thus the need for additional ventilation capacity.

2.3 Current and future UK uptake of dust abatement technologies

In the UK, farms operating with an Environmental Permit in 2008 are obliged to demonstrate some measure of dust management, but little use is made of more complex systems based, for example, on dry filters or wet scrubbers. However, it is likely to be the requirements for odour and ammonia reduction that precede the drive to reduce dust, and ultimately dictate the abatement systems employed in the future.

Control-at-source methods are limited in the amount of dust they can remove. However, they make a contribution to dust control where they are part of normal flock management techniques. Most farms already ensure good quality feed pellets are fed to birds where appropriate, using feeders that do not break up the feed and are not over-filled. Dust extracted bedding material is most often used because it is better for the birds and affordable. However, more specific management techniques to reduce dust, such as modifying bedding materials by humidification, or by spraying with oil or water will only be adopted if it is proved to have no adverse effect on general management or bird welfare in a commercial situation through, for example, reducing litter quality. It must also be cost effective to implement.

External, end-of-pipe technologies are currently limited to diverting dust from the roof or ground to a form of bio-filter, or they use dispersion and dilution into the atmosphere. Dry, wet and bio-scrubbers are more readily available elsewhere in Europe and tend not to be manufactured in the UK. At the Agromek 2006 show, at least five different European companies exhibited various air purification systems for livestock housing, including pigs and poultry. Although some 'stand-alone' units can be fitted retrospectively to many existing houses, others can only be integrated with new builds. The capital cost of installing abatement systems is estimated to be £1 per 3 – 4 m^3 of air change, i.e. volume of air treated, for wet scrubbers and £1 per 30m^3 of air change for dry filter systems.

3. Methodology

3.1 Selection of poultry production sites

The ban on the use of conventional egg production cages from 2012, and consumer led increased for extensively-produced egg and meat products, is changing the mixture of poultry production systems in the UK, which vary greatly in type and scale. New, affordable and proven technologies are also implemented, such as the use of 'tunnel' ventilation for hot weather. These also change the type of buildings used and potentially the emission of aerial pollutants such as dust and bioaerosols.

The following main types of poultry production system were selected for monitoring:

- **Litter systems (broilers) -** Broilers represent a significant proportion of the UK poultry population. They are floor reared on litter and therefore a potentially significant source of dust.
- **Egg production from layers in cages** – Whilst production of eggs from cages has been declining in the UK in preference to free-range production, it is still a major sector of the poultry industry as a whole.
- **Egg production from free range layers -** As this sector is increasing and may continue to increase, it was important to monitor dust output from floor-reared layers on a mixture of litter and slats.

The two abatement methods assessed for there efficacy in removing dust were:

- **dust trapping system** - directing the exhaust air down onto a water bath and then redirecting the air through 180degrees up into the air to disperse any pollutants further.
- **dry filter system (StuffNiX)** -, bank of paper filters, placed in a plenum chamber in front of the exhaust fans (Big Dutchman Gmbh).

In principle both systems can be retrofitted to any building with gable end fans, although the dry filter option will be more costly to retrofit.

Two farms were selected from each production type. In addition two farms fitted with a dust abatement technique were identified. Each farm was sampled twice, once in winter and once in summer (Table 3.1).

The monitoring sites were selected for their production system and secondly on criteria that would make the practical aspects carrying out the monitoring more straight forward. Preference was given to farms with powered ventilation, without obstructions down-wind, no or low external sources of dust up wind of the farm, access to the extractor fans for sampling, access for the mobile laboratory and an adequate power supply for the instrumentation. The selected farms were as new and as up-to-date as possible with regards to equipment and systems installed. Feeding, drinking, lighting and climate control were fully automated. Specifically, broiler houses were clear-span, constructed from a steel frame with insulated composite panels, fitted with pan feeders and modern nipple drinking system. Caged housing was fitted with belt-cleaned (enriched) cages with manure drying facilities and automatic egg collection. Free range houses were static and purpose build, constructed to high standards from wooden frame and cladding, with two-thirds slat and one-third litter on the floor and an automated nest system. Because the houses were relatively modern (possibly with the exception of Farm A), the emission factors derived here are expected to be more representative of current and future emissions than of past emissions.

In broiler production, dust concentrations were expected to be at or near peak towards the end of the 35-42 day crop (*Roumeliotis and Van Heyst*, 2007). Therefore, the broilers age was between 25-30 days old at the start of monitoring, so that the birds were large enough to be a representative sample, whilst avoiding thinning events (usually at 32 days of age). The layers were adult in full lay, giving a 55 week window for sampling.

Table 3.1 Farm type selected and dates of visit

Farm ID	Farm type	Winter	Summer
A	Cage egg	13 Feb 2007	n/a
B	Broiler	22 Feb 2007	18 June 2007
C	Free - Range egg	15 March 2007	4 June 2007
D	Cage egg	12 Nov 2007	3 June 2008
E	Free - Range egg	3 Dec 2007	30 June 2008
F	Broiler	4 Feb 2008	9 May2008
G	Broiler U-bend dust abatement	25 Feb 2008	8 July 2008
H	Broiler StuffNiX dust abatement	n/a	8 Sept 2008

A full description of each farm is given in Appendix A and a short synopsis is given below.

Broilers

Broiler production B, a modern large facility with six adjoining buildings, housed 56,043 birds on chopped straw. Ventilation was provided through ridge extraction (winter) or tunnel ventilation (summer). Air inlets were in the side wall.

Broiler production F, a modern new facility with two adjoining buildings, housed 33,600 birds on wood shavings. Extractor fans were fitted in the gable end with both "winter" air inlets and "summer tunnel" inlets in the side wall. A basic dust capture system deflecting the air downwards onto a water trap (15 cm deep pit containing water) was fitted to the building, but the water trap was not in use. This was not considered to be an effective abatement system.

Caged layers

Cage egg production A, the oldest building surveyed, a converted deep pit building, housed 39,320 layers in enrichable cages on two floors. Cages were fitted with manure removal belts and a manure drying system, but the latter was not in use at the time of sampling. Air inlets were in the ridge and extractor fans were fitted in the side wall at ground level.

Cage egg production D, a recently converted deep pit building, housed 47,150 birds in 60-bird colony units on two floors. Cages were fitted with manure removal belts and manure drying system. Conventional roof extractor fans and low pressure fans in the gable (tunnel ventilation in summer) were used with air inlets in the side walls and opposite gable end (tunnel ventilation only).

Free-range layers

Free range house C was of wooden construction with a concrete pit under wooden slats and a single tier of nestboxes along the centre of the house. The 4,650 hens had access to separate scratch areas with chopped straw either side of the slats and a large outdoor range. Air inlets were in the side wall and extractor fans in the ridge.

Free range house E, was also of wooden construction on a block wall and concrete base, housed 16,000 birds on plastic slats and two tier nestboxes offset from the centre line of the building. The scratch area with shavings as well as the range was to one side of the house only.

Abatement

The abatement systems were both fitted to modern broiler houses. Broiler production G abatement, was almost identical to F, housing 31,375 birds, but had an improved dust abatement system fitted, where air was deflected downwards onto a water trap (identical to farm F), and then upwards (U bend, unlike farm F), but again the water trap was not in use (see Figure 3.1).

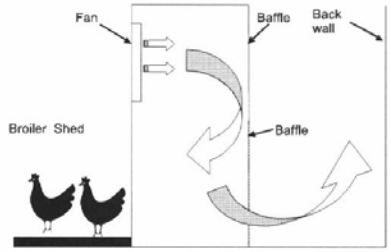


Figure 3.1 Schematic of the abatement system installed at farm

Broiler production H, was a newly built facility with of four identical buildings, housing 38,250 birds each on wood shavings. Air inlets were in the roof, through combined air inlet and recirculation chimneys and "tunnel" inlets in the side wall at the far end of the building only. Extractor fans were in the gable end of the building. A "StuffNiX" (Big Dutchman Ltd, http://www.bigdutchman.com/bd_infos/produkte/MagixX-StuffNiX-e.pdf), Figure 3.2, dust reduction system was fitted before the gable wall with the fans.

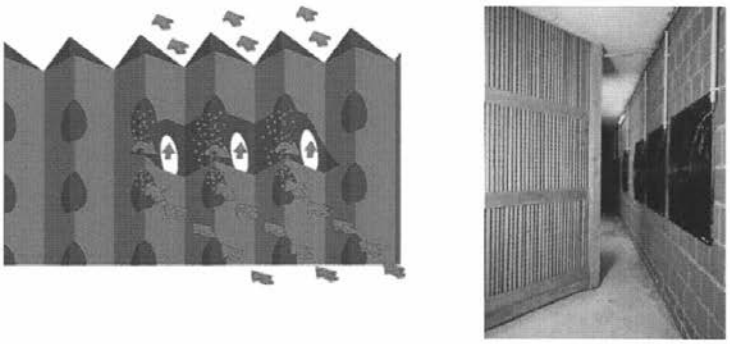


Figure 3.2 Schematic of the StuffNiX abatement system and installed in a broiler house

3.2 Measurement locations and time

Measurements were made in ambient air outside (upwind and at several distances downwind) the chicken houses, inside the chicken houses and at one or two ventilation fans. Where possible a fan was chosen that was operated continuously, rather than switched on and off depending on the environmental conditions. Measurements were made over a period of two to three days during each farm visit. Separate measurement were made during the light (day time) and dark (night time) periods for the birds. These periods were not necessarily during the actual day and night times.

3.3 Measurement techniques and approaches, physical and chemical characterisation

The aerosol mass loading was measured with a TEOM Ambient Particulate Monitor with a PM_{10} head (Thermo Electron), and by gravimetric analysis of samples from two $PM_{2.5}$ and two PM_{10} lowvol samplers (Partisol 2000, R&P) as well as two 8-stage Micro Orifice Uniform Deposit Impactors (MOUDI Model 100, MSP Corporation).

Particle size distributions were measured with a combination of two Aerodynamic Particle Sizers (APS), 0.7 to 20 μm (TSI APS 3321), an Ultra-High Sensitivity Aerosol Spectrometer (UHSAS), 0.06 – 1 μm; (Droplet Measurement Technologies) and a Differential Mobility Particle Sizer (DMPS), 0.02 – 0.4 μm; (Williams, 2001). For measurements at the fan outlets, short sample air inlets were mounted into the air flow, with diameters chosen to provide approximately isokinetic sampling conditions. The flow from the inlet was then directed into the MOUDI, the lowvol sampler (via a $PM_{2.5}$ cyclone and a Chemcomb PM_{10} inlet) and the APS systems. However, as the fan speed was often variable, some non-isokinetic sampling was to be expected.

The composition of sub-micron aerosol was monitored using and Aerodyne Aerosol Mass Spectrometer (Q-AMS), based on a quadrupole MS [*Jayne et al.*, 2000]. This instrument provides a quantitative measurements of the concentrations and size-distributions of non-refractory (NR) aerosol components (defined as those that volatilise at 600°C) in the size-range 0.06 to 1 μm, with emphasis on SO_4^{2-}, NH_4^+, NR-NO_3^-, NR-Cl^- and total organic aerosol mass (OM).

Using an automated switching system, the Q-AMS, UHSAS and DMPS sub-sampled from three 3/8" OD copper tubing from an ambient sampling point (outside the barns) and the two fan locations used for the physical measurements. Each of the inlet lines was protected with an inlet cyclone ($PM_{2.5}$ at 16.67 lpm, but operated at 10 to 12 lpm, providing an effective cut-off of 3.5 μm) and continuously flushed at a flowrate of approximately 8 lpm.

The lowvol samples and selected MOUDI runs were chemically analysed for major ions (SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}) or a total of 26 trace metals by ICP-MS including As, Cd, Cr, Cu, Pb, Ni, Zn and V.

At selected farms, particles were passively collected by deposition onto carbon stubs for subsequent analysis by scanning electron microscopy (SEM). Additionally, elemental analysis was performed on the carbon studs using Energy Dispersive X-Ray Fluorescence Spectrometry (EDX).

Measurements were filtered for problems such as power disruptions, equipment failure and human error. Measurements during which the lowvol sampler failed to maintain its flow rate (thus changing the cut-off diameter of the $PM_{2.5}$ and PM_{10} inlets), and runs where $PM_{2.5}$ mass concentrations exceeded PM_{10} were rejected.

The APS instruments measure the number size-distribution based on aerodynamic diameter (i.e. the physical diameter of a unit density sphere which settles with an equivalent velocity of the particle in question). These spectra can easily be converted into surface area or volume distributions assuming spherical shape, but to convert into mass distributions (e.g. for $PM_{2.5}/PM_{10}$ comparisons) the true density of the particle was required. This density was estimated by comparing APS data converted to unit density mass distributions with instruments which directly measure mass (see Appendix B for example). Where possible, the TEOM was used to calculate densities for PM_{10} APS data as this offers a higher temporal resolution than the second option – using the results from the lowvol and MOUDI runs, which had to be used for those periods without concurrent TEOM measurements. One single average density was derived for each farm visit. While the mass loading measured

with APS is therefore not fully independent of the other techniques, it provides additional information on the size distribution.

3.4 Measurement techniques and approaches, microbiological characterisation

Environmental (static or fixed point) samplers were taken during dark and light periods for the birds. Static samplers (Anderson and Partisol samplers), were placed side by side at 50 m downwind from the shed/fan being monitored and also where possible at 50-100 m intervals downwind of the activity, up to a maximum of 400m. Control samples were also taken 50 m upwind of the activity to measure background bioaerosol levels unaffected by emissions from the poultry building. Inside the building, fixed point samples were taken in general house areas and in, or as close as possible to, the fan unit.

The six-stage Andersen impaction sampler collects airborne particles by impaction onto the surface of agar plates placed under six stacked sieve plates, which are progressively smaller from top to bottom, so that particles collected are separated into six size ranges that can be equated with deposition in the human lung as follows:

- Stages 1 and 2 collect particles greater than 7 µm in aerodynamic diameter, equating to nasal deposition.
- Stages 3 and 4 collect particles 3 to 7 µm, equating to bronchial deposition.
- Stages 5 and 6 collect particles smaller than 3 µm, equating to alveolar deposition.

Bioaerosols were collected onto half-strength Nutrient agar and Malt agar. To ensure sufficient loading of the agar plates, the samplers were run for three to fifteen minutes depending on the distance from the poultry house and hence the expected level of dust emission. Suction for the samplers was by generator powered vacuum pumps run at the required volume of 28.3 l/min. The size distribution data obtained have been reported in the previous section.

Partisol samplers (Models 2000 and 2005) were used to collect PM_{10} and $PM_{2.5}$ particulate matter onto 47 mm filters at a flow rate of 16.7 l/min (1 m^3/hour). The Partisol 2000 and 2005 sampler operate in the same way but the 2005 model includes an automatic filter change mechanism, which allows timed sequential sampling, important where sample filters may become overloaded. Filters from the Partisol samplers were placed in pyrogen free tubes and the collected deposits were extracted by tumbling at room temperature for 2 hours in 10 ml of endotoxin free 50 mM Tris buffer (Cambrex). The resulting suspension was then divided to provide samples for endotoxin analysis and microbial enumeration (see Appendix D). Predominant bacterial and fungal colonies were identified by gross morphology, microscopic examination and DNA analysis using polymerase chain reaction (PCR) techniques (see Appendix D).

3.5 Measuring ventilation rate and ammonia concentration

The building ventilation rate was measured with a constant release tracer technique (Demmers *et al.*, 2009). A known amount of sulfurhexafluoride (SF_6) gas was released along a line source in the centre of the poultry house and the ventilation rate was derived from the SF_6 concentration, measured using a gas chromatograph, at the air outlets and corrected for the ambient concentration. Ammonia concentration was measured using a chemiluminesence NO_x analyser following catalytic conversion of ammonia to nitric oxide (NO) at 750 °C.

Emission factors (*EF* in mg / (LU hr)) were calculated by multiplying concentration (corrected for background concentration) in µg/m^3 with the ventilation rate (m^3/hr). Emission factors per livestock unit (LU), equivalent to 500 kg of live weight, were calculated taking into account number of birds per barn and their average weight.

3.6 Assessing efficacy of abatement technique

The measurement techniques and approaches were identical to the other farms (see above), but only a subset of instruments was used, namely APS, TEOM, Partisol and MOUDI to characterise the dust and the tracer technique to measure ventilation rate and ammonia analyser to measure ammonia concentrations.

At Farm H, equipped with a filter, concentrations were measured in the exit air stream both upwind and downwind of the filter and the efficacy was quantified from the difference in concentrations. By contrast, the abatement of the outlet baffle of Farm G had to be derived from concentration measurements up- and down-wind of the baffle wall. However, the concentration downstream is not only reduced by the capture of dust by the baffle, but also by dispersion and down-mixing of clean air. When assessing the abatement potential of outdoor systems this dilution must be taken into account, by back-calculating the abatement concentration to a pre-dilution value at the fan where a comparable instrument was located. In practice, this was achieved by measuring the SF_6 tracer gas both at the fan outputs (*F*) and at the location of abatement (*A*) and correcting the concentration after abatement (χ_A) for the dilution effect:

$$\tilde{\chi}_A = \chi_A \times \frac{S_F - S_{bgr}}{S_A - S_{bgr}} + \left(1 - \frac{S_F - S_{bgr}}{S_A - S_{bgr}}\right)\chi_{bgr}$$

where S_F, S_A and S_{bgr} are the SF_6 concentrations at the fan, the post-abatement measurement point and in the background air, respectively. χ_{bgr} is the concentration of the air that is diluting the measurement, approximated by the concentration measured upwind of the poultry house.

Monitoring a control house, i.e. without an abatement system fitted, at the same site was neither necessary as no changes were made to the management of the house, nor possible as all houses of the same type on site were fitted with the abatement system.

4 Results

4.1 Physical and chemical characterisation

4.1.1 Mass concentration

The mass concentrations in Table 4.1 are the ranges measured using all particle instruments encountered at each farm type, segregated according to lighting regime and season. The broilers gave the highest PM_{10} concentration, reaching 2990 $\mu g/m^3$ during the summertime when the lights were on; the lowest PM_{10} concentration (20 $\mu g/m^3$) was measured during a visit to a caged farm. The broiler and caged-layer farms also produced the highest and lowest concentrations of $PM_{2.5}$ with values of 655 $\mu g/m^3$ (winter-time dark period) and 23 $\mu g/m^3$ (summer-time dark period), respectively. On average there was a 30% reduction in particle concentrations during dark periods compared with the same location during light periods, although notably there was an increase for $PM_{2.5}$ & PM_{10} at the broiler farms, probably due to the influence of the very short dark period of < 60 min at farm F, during which the dust does not settle fully. Discarding this anomalous point results in an average decrease of 51% between light and dark periods overall, which may be split further seasonally, to show a 60% lowering of dark concentrations in summer compared with a value of 40% for wintertime.

When light and dark period data are considered together, but split according to a winter or summer visit, a 43% average increase during winter visits compared with summer results. Separated further into light and dark components, the average seasonal influence during the day is negligible, while the increase in the average is dominated by a marked winter increase during dark periods of 86%.

Table 4.1 Mass concentration ranges ($\mu g/m^3$) measured at all locations at all farms.

			$PM_{2.5}$			PM_{10}		
		Farm Type	**min**	**max**	**mean**	**min**	**max**	**mean**
Light	***Summer***	*Broiler*	255	440	365	850	2290	1550
		Layers - battery	39	409	142	49	775	375
		Layers - Free Range	105	190	145	220	1240	682
	Winter	*Broiler*	110	366	255	352	1340	807
		Layers - Battery	147	167	157	302	542	422
		Layers - Free Range	73	306	194	509	1700	791
Dark	***Summer***	*Broiler*	112	296	189	411	896	586
		Layers - Battery	23	152	66	20	241	118
		Layers - Free Range	27	262	65	109	449	221
	Winter	*Broiler*	630	655	642	522	1020	793
		Layers - Battery	57	63	60	178	264	221
		Layers - Free Range	47	112	110	208	881	432

Diurnal variability can clearly be seen on time series trends and examples are given in Figure 4.1, which exemplifies two contrasting time series of ambient in-shed concentrations and size distributions of coarse particles at (a) broiler farm B and (b) free-range layer farm C. During dark periods in the broiler farms the lights are quickly switched off, resulting in a rapid transition from awake to sleep state and simultaneously bird activity quickly declines. In contrast, bird activity gradually slows in the free-range layer farm mimicking the slow change from light to dark conditions. In addition, prior to the final decreasing of particle concentrations, a clear spike is observed (Figure 4.1b at 20:30), related to observed bird activity due to final feeding and subsequent competition for roosting positions. Whilst the overnight concentration increase is due to an unusual additional feeding period in the night whilst the birds come into lay. On return of the light period, a similar pattern is seen in reverse – with concentrations slowly increasing in Figure 4.1b as the birds wake up more gradually, in contrast to the rapid return to 'light-time' concentrations shown in Figure 4.1a. Also apparent in Figure 4.1a are periodic spikes. The fact that these were not seen at any of the other broiler farms visited rules out feeder activity as a potential cause. Instead they appear to correspond to the use of differently coloured lighting to induce bird movement, which was only used at this farm. As one might expect, the concentrations measured by the different instruments agree more closely during dark periods when less bird movement increases the homogeneity of the air, during the light period large concentration gradients caused by movement appears to have a large effect, even over the short distances between inlets.

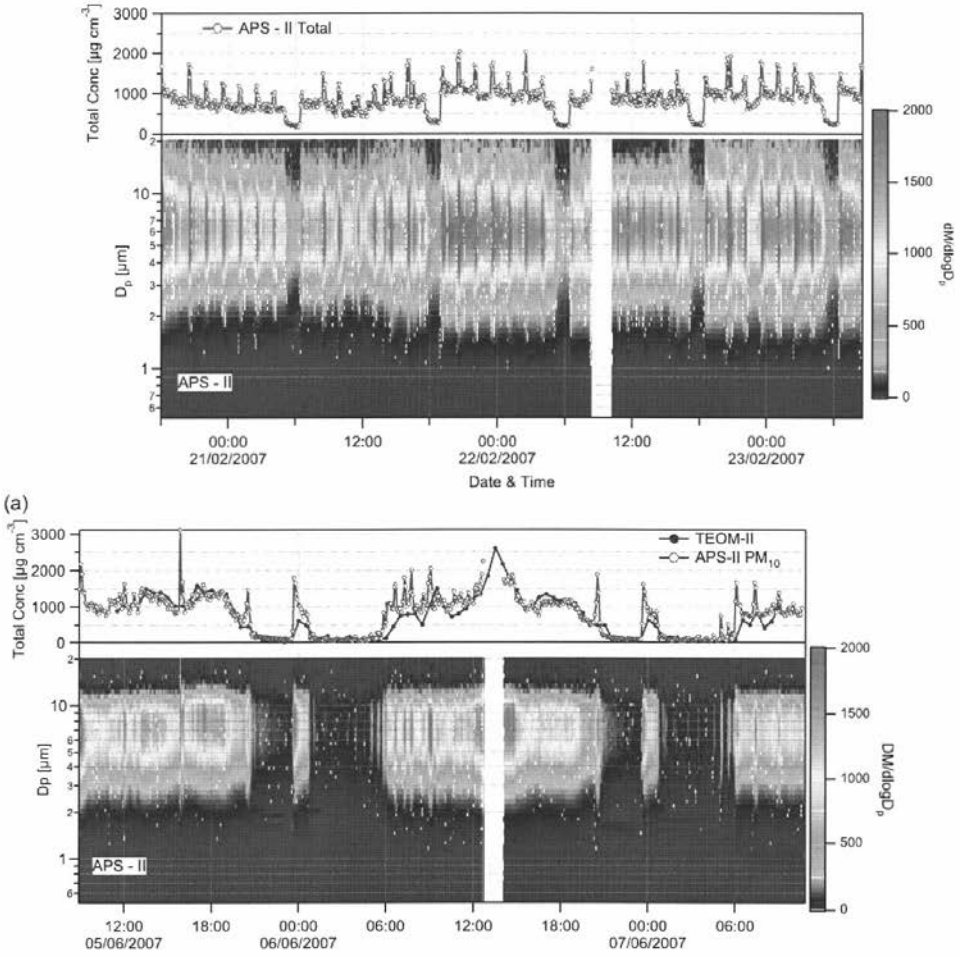


Figure 4.1 Time series of mass concentration data showing (a) Total measured APS and TEOM PM_{10} distributions from broiler farm B and (b) APS and TEOM PM_{10} distributions from free-range layer farm C. In both plots the contrast between dark and light periods can be clearly seen – around 06:00 and 18:00 in (a) and 19:00-07:00 hrs in (b). Spikes in (a) correspond to the use of coloured lighting designed to stimulate bird activity. For comparison, the APS total concentrations shown in (b) are summed over the PM_{10} range and TEOM data are plotted on the same axis.

4.1.2 Average size distributions; coarse particles

The two example time-series of mass size distributions (Figure 4.1) already indicate that particle sizes differed between farms. In this case, free range house C showed larger particles in the exhaust air than broiler farm B. This may be governed by the dimension of the building, position (ridge fans broiler house higher) and speed of the fans (e.g. larger particles will reach low or side vents more easily than high ridge vents) and the larger contribution of bedding material to the resuspended dust at the broiler farm, which possibly contributes smaller particles than feed and dander derived particles.

The APS mass distribution plots shown in Figure 4.2, contain particle concentrations measured on both APS instruments and averaged according to farm type, season, and lighting state. Standard deviations of all the averaged data are plotted as bars, although the logarithmic y-axis enhances the appearance of these bars, the reasons mentioned in the preceding paragraph will contribute to the variability between measurements, as will the poor counting statistics of the APS at the extreme ends of its size range. From these plots, the general unimodal distribution of particles at all farm types is apparent, and yet peak at different sizes – 5.8, 5.0 and 4.3µm for free

range layers, broilers, and cage farms respectively. These differences may again be partially explained by sampling location and litter conditions, but the consistency within farms of the same type indicates differences between the farm types may be important – e.g. such as the movement freedom and physical condition of the birds resulting in more larger particles being generated.

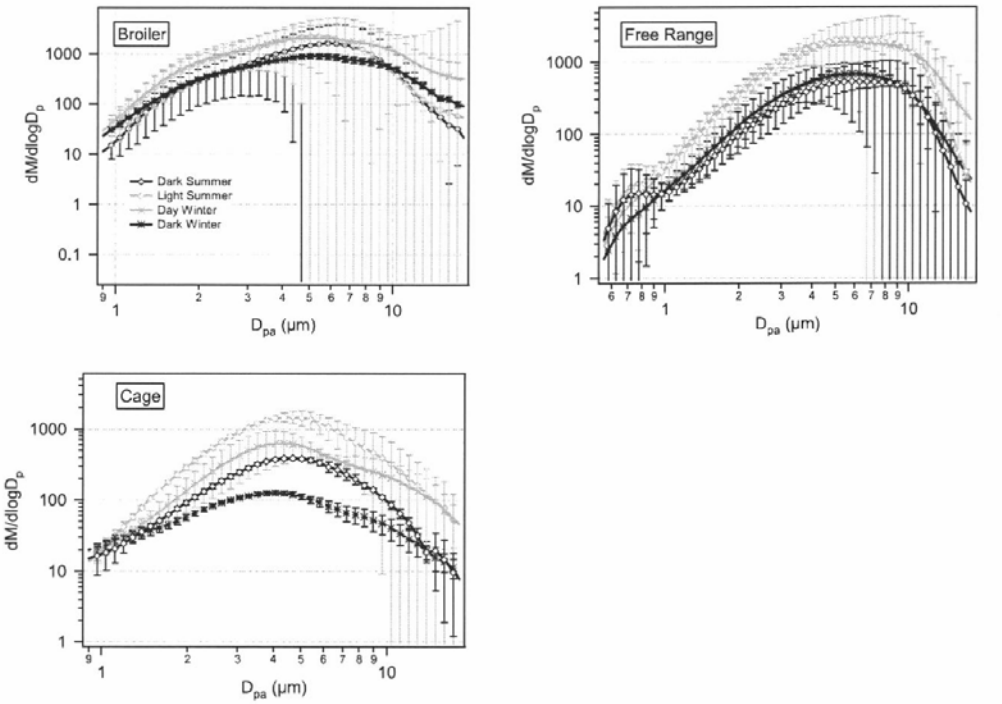


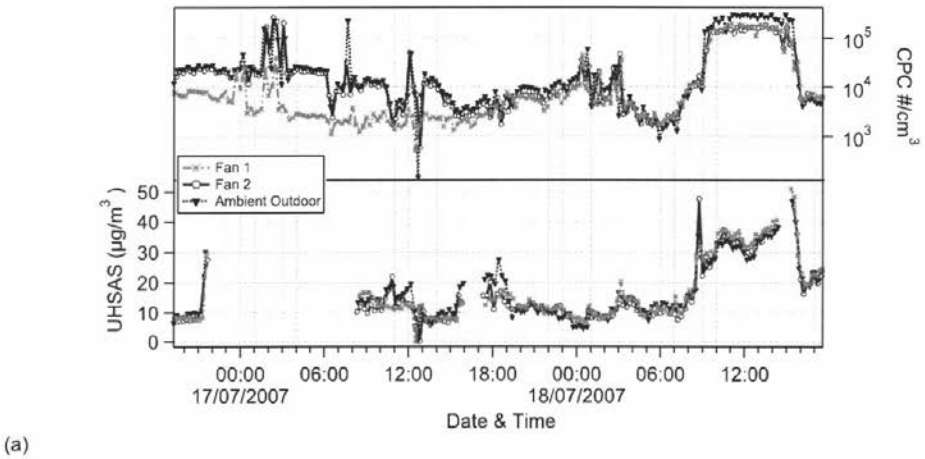
Figure 4.2 Aerodynamic particle size distributions from APS measurements averaged according to farm type, light regime (light or dark), and season (summer or winter). Masses were calculated using the densities shown in Appendix B. Bars indicate 1σ.

4.1.3 Average size distributions; fine particles

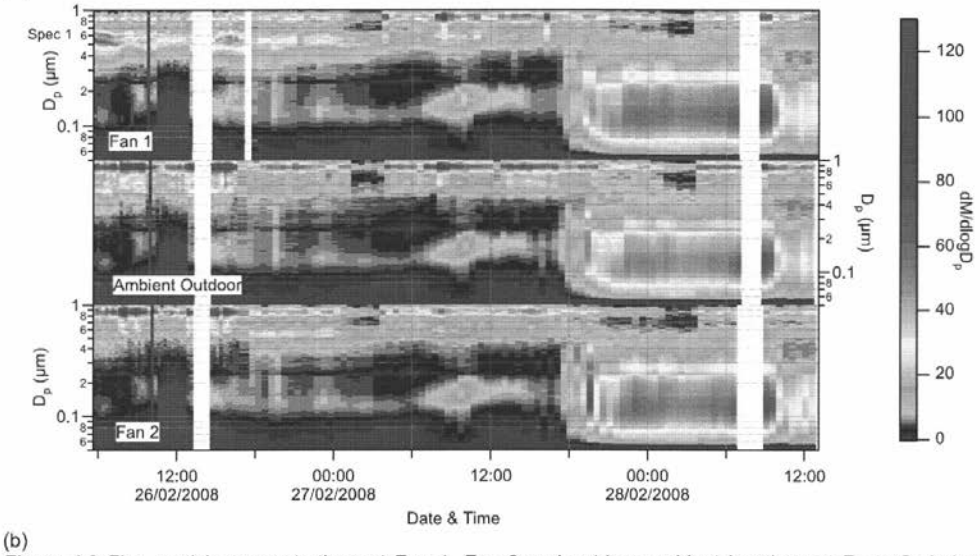
During the course of the investigation it became apparent that sub-micron aerosol loading measured inside the barn was determined by external ambient concentrations – Condensation Particle Counter (CPC) measurements recorded higher number concentrations from the ambient channel (Figure 4.3a) compared with the internal measurements, and the total sub-micron mass measurements from the UHSAS (Figure 4.3b) produced very similar concentrations on all channels. This unity between measurements was observed during all visits and is further supported by the chemically resolved Q-AMS measurements in Section 4.1.4 below. Figure 4.3b displays size-resolved UHSAS data for the same period at an example farm for three measurement locations, and again demonstrates very little difference between the fan locations and outside air.

4.1.4 Chemical composition of the poultry dust - sub-micron particles

An example time-series of the non-refractory sub-micron aerosol composition measured with the Q-AMS is shown in Figure 4.4. The measured concentrations at the three sampling points are identical within the measurement uncertainty, indicating that there was no evidence of significant emissions of any of the sub-micron aerosol components resolved by the Q-AMS, corroborating the findings of the sub-micron particle number measurements by UHSAS. In some situations concentrations tended to be somewhat lower at the fans than the ambient concentration. Losses in the copper lines were not fully characterised in this study and could have contributed to this effect. Alternatively, particle deposition of ambient sub-micron aerosol inside the barns or coagulation growth to super-micron aerosol (given the high aerosol concentration) may also explain this observation. Given the insignificance of the emissions resolved by the Q-AMS, these measurements were abandoned halfway through the measurement programme. In particular, these measurements indicate that there was no significant gas-to-particle formation within the poultry houses from the high NH_3 onto existing sub-micron aerosol.



(a)



(b)

Figure 4.3 Fine particle concentrations at Fan 1, Fan 2 and outdoor ambient locations at Farm G during the summer visit with (a) the CPC number concentrations in #/cm^3 and total UHSAS concentrations in µg/m^3 and secondly (b) the UHSAS mass distributions. For calculating mass distributions, a density of 1g/cm^3 was used.

4.1.5 Concentrations and size-distributions of aerosol chemical components

A total of eleven MOUDI runs were analysed for major inorganic ions (SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}). The size distributions averaged over all farms, locations and conditions are shown in Figure 4.5, while the concentrations are summarised in Table 4.2. The levels and size-distributions of NH_4^+ and SO_4^{2-} are characteristic of ambient concentrations, with almost all material found in sizes < 1 µm. It is well documented that volatile NH_4^+ compounds (NH_4NO_3 and NH_4Cl) may volatilise during MOUDI sampling, especially from the smaller impactor stages. However, combined with the AMS measurements (which do not suffer this artefact), the measurements show that there is neither much sub-micron NH_4^+ nor that there is much super-micron NH_4^+. It has been suggested that dust filtration at the outlets of poultry houses could abate total NH_x emissions as a significant fraction of the NH_3 emitted may partition onto the aerosol (Takai, 1999). Based on the measurements reported here this seems highly unlikely.

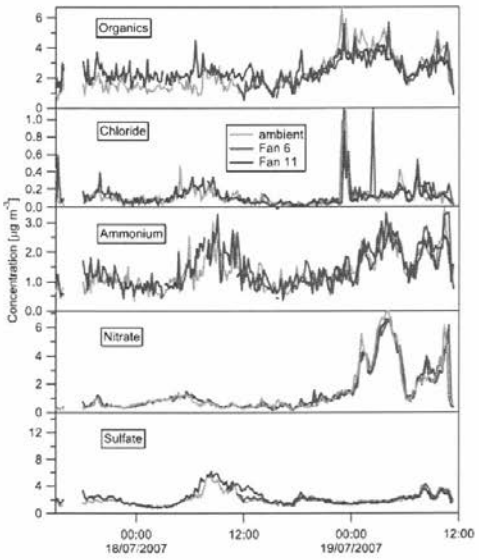


Figure 4.4 Farm B (summer) comparison of non-refractory submicron particle concentrations in the ambient air and the air at two outlet fans. The close agreement between concentrations at the outlets and in ambient air indicates that poultry rearing does not cause emissions of these components.

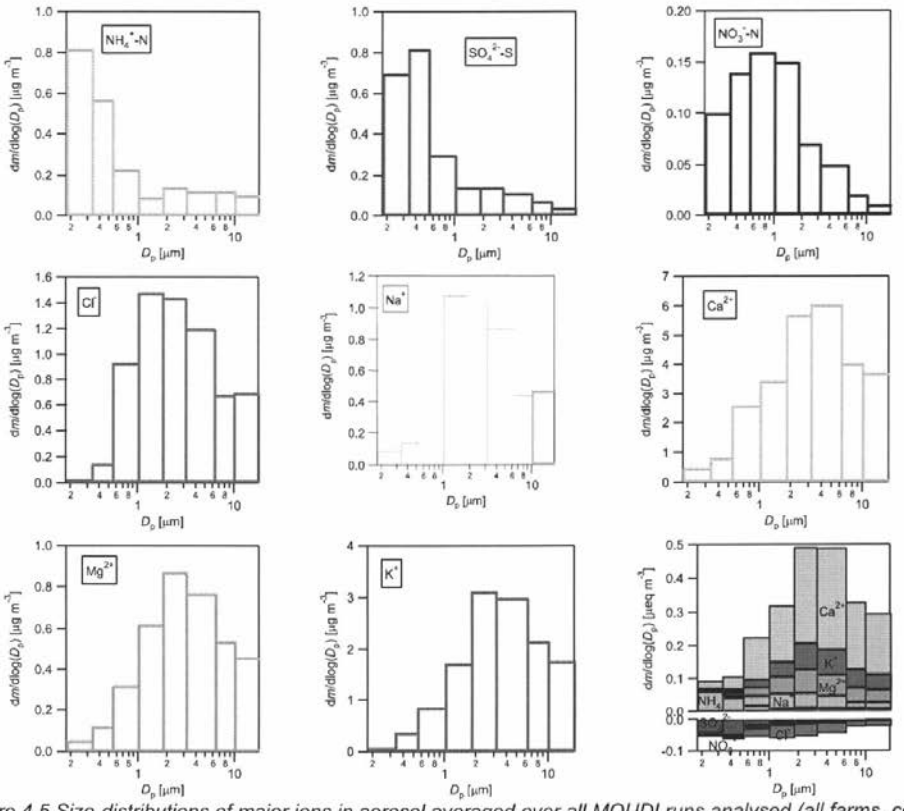


Figure *4.5 Size-distributions of major ions in aerosol averaged over all MOUDI runs analysed (all farms, condition and positions) and the stacked size-distributions of total cations and anions measured (in µeq m^{-3}).*

Size distributions of Cl^- and Na^+ follow each other and are contained in the size range expected for sea salt. The base cations Ca^{2+}, Mg^{2+} and K^+ are very high compared with typical ambient air concentrations and contained in the size-fraction associated with the poultry dust. Figure 4.5i compares the total resolved positive and negative equivalent ion concentrations. The measured anion charge only balances between 61% down to 7% of the resolved cation charge, depending on the size fraction. This indicates that most of the coarse base cations were not charge-balanced by the anions reported here. Major missing anions are likely to include phosphate (PO_4^{3-}) and organic anions such as carbonate (CO_3^{2-}).

In addition, to the average concentrations and their variability, Table 4.2 also reports the fractional contribution of the measured ions to the measured PM. These components were not measured in the ambient air upwind of the poultry houses. From the concentrations and size-distributions it is likely that SO_4^{2-}, NO_3^-, Cl^-, NH_4^+ and Na^+ mainly derive from the contribution of outside air, while K^+, Ca^{2+} and Mg^{2+} mainly derive from the poultry dust.

Table 4.2 Concentrations of major inorganic ions averaged over all farms. Shown are the actual concentrations in PM and the ion fraction, i.e. the ion concentrations normalised by PM mass concentration (in %). Values in parentheses are standard deviations between runs (all farms and positions).

	PM Concentration [µg m^{-3}]				PM Fraction [%]			
	light		dark		light		dark	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
SO_4^{2-}-S	0.52 (0.52)	0.76 (0.66)	0.43 (0.51)	0.56 (0.56)	0.39 (0.30)	0.20 (0.14)	0.69 (0.92)	0.27 (0.32)
NO_3^--N	0.24 (0.18)	0.27 (0.21)	0.25 (0.16)	0.29 (0.22)	0.25 (0.42)	0.09 (0.09)	0.45 (0.35)	0.19 (0.18)
Cl^-	1.37 (1.43)	3.38 (2.85)	1.49 (3.18)	2.26 (1.86)	0.80 (1.13)	0.88 (0.87)	1.39 (2.07)	0.96 (0.82)
NH_4^+-N	0.65 (0.65)	1.07 (1.07)	0.59 (0.80)	0.86 (0.81)	0.39 (0.68)	0.20 (0.16)	0.85 (1.48)	0.37 (0.43)
Na^+	0.79 (0.62)	1.72 (1.50)	0.54 (0.48)	1.19 (0.85)	0.69 (0.70)	0.41 (0.29)	0.97 (1.08)	0.56 (0.43)
K^+	2.81 (3.21)	10.2 (11.8)	1.12 (1.70)	5.24 (6.01)	1.70 (2.03)	1.68 (1.07)	0.65 (1.09)	1.27 (0.79)
Ca^{2+}	3.46 (2.83)	11.4 (13.2)	1.13 (0.98)	6.00 (4.33)	2.40 (1.48)	2.46 (1.71)	1.63 (1.43)	2.80 (1.66)
Mg^{2+}	0.76 (0.60)	2.25 (2.41)	0.34 (0.27)	1.13 (1.08)	0.49 (0.26)	0.40 (0.22)	0.39 (0.25)	0.42 (0.23)
Total#	12.6 (8.66)	33.9 (31.0)	7.81 (5.61)	19.9 (14.4)	8.94 (4.66)	7.12 (3.38)	10.3 (6.52)	8.18 (4.42)
Σ anions*	0.088 (0.086)	0.16 (0.14)	0.086 (0.13)	0.12 (0.10)				
Σ cations*	0.39 (0.35)	1.17 (1.30)	0.18 (0.19)	0.64 (0.55)				
anions/cations	0.23 (0.25)	0.14 (0.11)	0.48 (0.69)	0.19 (0.19)				

The total includes the full molecule mass of SO_4^{2-}, NO_3^- and NH_4^+; * Ion sums are provided in µeq m^{-3}.

Distribution of trace metals over the size fractions (Appendix C, Figure C.1) of the dust differed greatly between elements: Co, Mn, Ti and Zn showed a large contribution from the coarse mode, which characterises the poultry emissions, suggesting that these metals were contained in the poultry dust itself. By contrast, Cu and Pb were dominated by smaller particles (< 2 µm), suggesting that these compounds probably originated from sources other than chicken dust (including ambient background and combustion sources sometimes found on farms). A third group of metals (e.g. Al, Cr and Ni) showed a very wide size distribution, while Fe showed clear distinct contributions from both modes.

In general, absolute concentrations (appendix C, Table C.1) are larger during the light period than during the night period, with the exception of Zn for which concentrations are similar and for Ba, Be, Cr and Ni for which larger concentrations were found during the dark period. When comparing $PM_{2.5}$ and PM_{10} as well as dark and

light concentrations, it needs to be considered that the sample populations are not equally distributed over the different farms. Nevertheless, metal concentrations in PM_{10} exceed those in $PM_{2.5}$ for most metals, which is most pronounced (at least 2/3 in coarse fraction) for Al, As, Ba, Cu (light only), Cr, Mn, Rb, Sr and Ti, suggesting that these mainly originate from the poultry dust. By contrast, the coarse contribution is small for Be, Cu (dark only), Pb and Sc, again suggesting that concentrations of these latter metals are dominated by fine aerosol from outside the poultry houses.

Emission factors could be reliably established for a limited amount of chemical components (Appendix C, Table C.2), which also includes a first estimate of UK metal emissions from poultry installations, for which our emission factors were upscaled with UK poultry numbers. When compared to the UK National Atmospheric Emission Inventory (NAEI), poultry husbandry accounts for 2% for Cu, 2.5% for Mg^{2+} and 4% of K^{+} of the estimated anthropogenic emissions.

All of the identified chemical elements analysed by the SEM\EDX (Appendix C.3) have relative maxima around the 10 µm size bin, illustrating these elements are most abundant within our defined poultry dust size range. Si is an abundant crustal material, Sm and Mg are minerals which may originate from the chicken feed and are know to be present in feed additives such as zeolites and Bactocell while Na may originate from sea salt transported into the poultry house from outside (see above). Ti and Al are not usually present in poultry feed and possibly originate from the feeder mechanisms.

4.2 Bioaerosol concentrations in and downwind of poultry houses

The measured concentrations of PM_{10}, bacteria, fungi and endotoxin are summarized in Tables 4.3 to 4.6, respectively. Included are the results for the internal and external locations using either the Partisol or Anderson samplers.

4.2.1 PM_{10} concentrations within and downwind of poultry houses

The concentration of PM_{10} emitted from poultry houses is highest for the broiler houses (Table 4.3) and this is evident from the higher concentrations of PM_{10} measured close to the buildings. However, in almost all cases the concentration of PM_{10} had dropped to background levels (50m upwind) at 100 m and for all cases at 200 metre distance from the buildings (Figure 4.6).

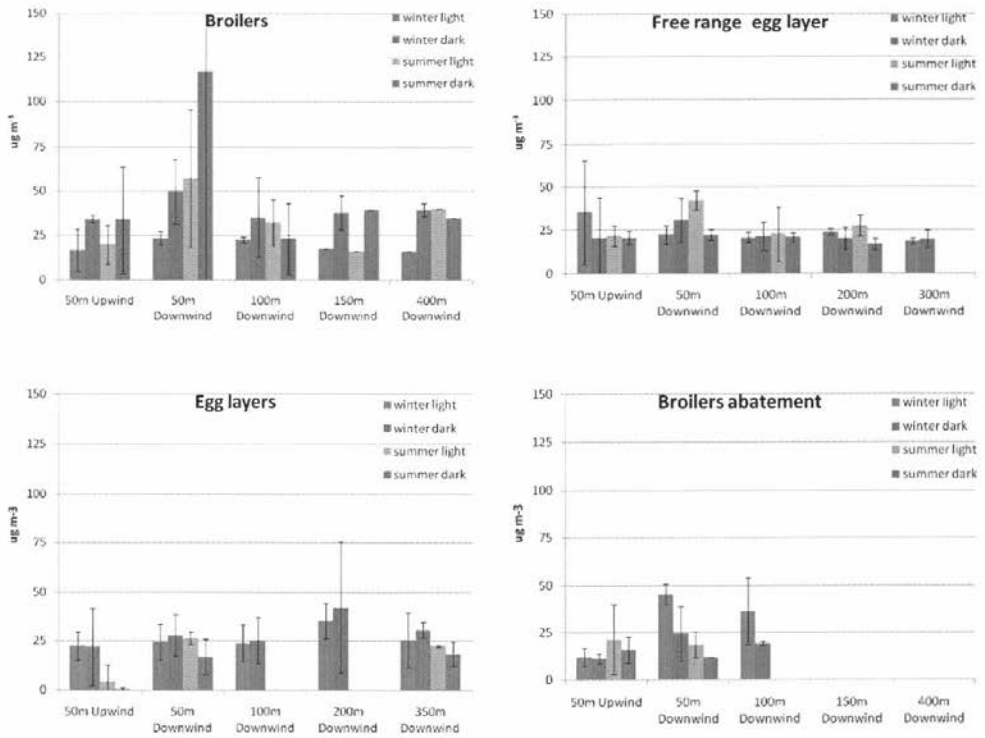


Figure 4.6 Average PM_{10} concentrations measured uning the paritisol samplers upwind and downwind from the poultry houses

Table 4.3 Mean daily PM_{10} concentrations [$\mu g\ m^{-3}$] derived from measurements using the static Partisol samplers (standard deviation in brackets).

Farm Type	Farm ID	Winter/ Summer	Light/ Dark	Upwind 50m	Inside house	Exit	Downwind Up to			
							50m	100m	150m	400m
Broiler	B	Winter	Light	18	1434 (40)	340 (104)	24	27	24	23
			Dark	54 (4)	695	792	59 (18)	51 (36)	60 (10)	60 (4)
		Summer	Light	18 (7)	922 (171)	212 (265)	23 (2)	38 (13)		
			Dark	37 (28)	574 (87)	35	149 (166)	11 (20)		
	F	Winter	Light	15 (12)		1396 (787)	22 (4)	18 (2)	10	9
			Dark	14 (0)		562 (242)	40 (20)	19 (9)	15	19
		Summer	Light	22 (15)		481 (305)	91 (76)	26	16	40
			Dark	31 (33)		928 (328)	84 (72)	35	39	35
Cage	A	Winter	Light	30 (7)	347 (182)	500 (694)	24 (10)	24 (11)	28 (6)	26 (14)
			Dark	34 (25)	120 (13)	205 (143)	33 (18)	32 (22)	26 (11)	31 (4)
		Summer	Light							
			Dark							
	D	Winter	Light	14 (8)	775 (28)	1301 (524)	25 (8)	24 (8)	43 (12)	
			Dark	10 (14)	123 (67)	723 (188)	23 (3)	19 (2)	58 (56)	
		Summer	Light	4 (8)		302 (221)	26 (3)			22 (1)
			Dark	1 (1)		264 (113)	17 (9)			18 (6)
Free range	C	Winter	Light	19 (0)	605 (43)	100 (40)	31 (6)	27 (3)	26 (0)	22 (2)
			Dark	31 (23)	184 (16)	47 (14)	29 (13)	32 (13)	29 (11)	28 (9)
		Summer	Light	24 (10)	1109	291	36 (7)	9 (23)		
			Dark	27 (7)	211 (5)	96 (69)	26 (3)	26 (4)		
	E	Winter	Light	44 (60)	858 (92)	466 (49)	18 (60)	19 (3)	16 (3)	15 (1)
			Dark	12	122 (20)	74 (129)	30	14 (3)	12 (1)	11 (1)
		Summer	Light	19 (2)	2977 (3667)		48 (2)	36 (8)	27 (6)	
			Dark	14 (0)	171 (214)		18 (0)	15 (1)	17 (3)	

4.2.2 PM_{10} bioaerosol concentrations within the poultry houses

With few exceptions, the bacterial, fungal and endotoxin concentrations inside the poultry houses were higher in the winter period compared with the summer, due to the lower ventilation rates. The dark periods showed generally lower bacterial counts compared with the light periods. Although the ventilation rates were

generally lower, the effect of the lower activity of the birds and hence the lower level of PM_{10}, outweighed the lower ventilation rate.

For caged farms, airborne internal bacteria concentrations ranged from 10^3 in the dark periods to 10^4 cfu/m^3 in the light periods (cfu = colony forming unit). For the broiler farms, airborne internal bacteria concentrations ranged from 10^4 to 10^6 cfu/m^3. For the free range farms, airborne internal bacteria concentrations ranged from 10 to10^5 cfu/m^3. Both latter farms had much lower concentrations in the winter period than the summer period, a reversal of what was expected. Increased summer concentrations could be influenced by more birds being out on the range, hence the average ventilation rates during the summer were about the same compared with winter, despite higher ambient temperatures. However, this did not explain in full the high levels during the summer, as lower animal numbers generally also impact on the dust generation, i.e. lower the dust concentration.

For the caged farms airborne internal fungi concentrations ranged from 10 to 10^2 cfu/m^3. On farm D the winter light period was higher than the summer light period. The winter light period was higher than the dark period on farm A.

For the broiler farms, airborne internal fungi concentrations ranged from 10 to 10^3 cfu/m^3. On farm B the summer and winter light periods were higher than the dark periods. On farm F, the fungi concentrations were higher in the winter light period than the summer light period and the summer dark period was higher than the winter light period

For the free range farms, airborne internal fungal concentrations ranged from 10 to10^4 cfu/m^3. On both farms C and E, concentrations in the summer light periods were higher than the winter light periods. On farm C, the concentration in the summer dark period was higher than the winter dark period. On farm E, the dark periods were similar at 160 and 164 cfu/m^3 for summer and winter, respectively.

For the caged farm C, the endotoxin concentrations ranged from 1 to 42 EU/m^3. For the broiler farms, airborne internal endotoxin concentrations ranged from 1 to 10 EU/m^3. Farm B had concentrations below 1 EU/m^3 in the summer. In the winter light period, an uncharacteristically high concentration of 88 EU/m^3 was recorded, whilst in the winter dark period a more realistic 4 EU/m^3 was measured. On farm F, the winter light and dark periods were higher than the summer light and dark period as expected and ranged from 1.5 to 28 EU/m^3.

For the free range farm C, the airborne endotoxin concentrations were higher in the winter than in the summer for both light and dark periods and ranged from 1 to 70 EU/m^3. On farm airborne endotoxin concentrations were much higher and ranged from 21 to 260 EU/m^3. Here, concentrations in the summer light period were higher than the winter light period and the winter dark period was higher than the summer dark period.

4.2.3 PM_{10} bioaerosol concentrations downwind of the poultry houses

As mentioned before, bioaerosol samples were not only taken inside the poultry houses and at the exhaust fans, but also upwind of the house and at several distances (50, 100, 200 and 300 m) downwind. Although an effort was made to work on isolated poultry houses, were possible, the results of the external sampling using either the Partisol or Anderson samplers, will be affected by the unquantified emission from neighbouring sheds and/or other sources on the site or in the vicinity of the experimental shed. Because bioaerosols diminish with distance from the source at distance it is far more difficult to substantiate the source of the bioaerosol. This must be taken into account when interpreting the results, particularly beyond the 50 m sampling point where other operations may contribute to the results. Although Andersen samplers are considered the gold standard bioaerosol sampler, in situations of high airborne concentration they are considered impractical due to overloading at short sampling times. Hence they were not employed for sampling internally nor at the fan at the poultry shed.

The concentrations of bacteria upwind, downwind, internally and at the poultry shed fan measured using either the Partisol or the Anderson sampler, are summarised in Table 4.4 and for free range house farm E in Figure 4.7. The airborne bacteria and fungi concentrations from the Andersen samplers are shown in Tables 5 and 6 respectively. In comparison to the PM10 samples, Andersen samples yielded 10-100x more cfu at the upwind and downwind positions. This is as expected due to direct impaction onto agar and no loss due to sample manipulation downstream of sampling. Results were more variable than with Partisol samplers, possibly reflecting the short sampling time and greater susceptibility to fluctuations in bioaerosol levels, but generally demonstrated that concentrations were higher at 50m downwind of poultry sheds than background (50m upwind) and generally declined to background again by 200m downwind.

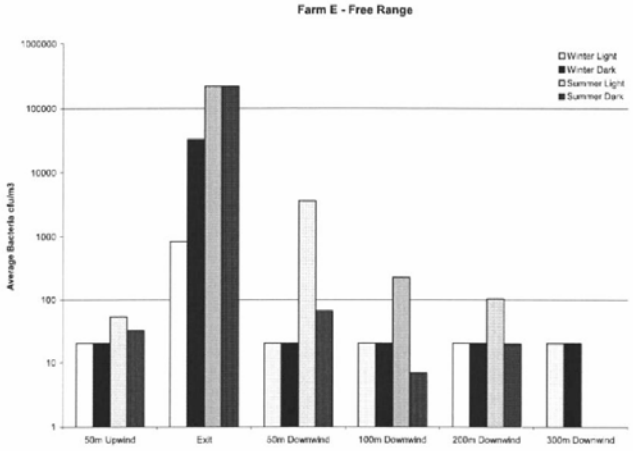


Figure 4.7 Overview of the daily Bacteria count in the PM_{10} samples taken at the specified location at free range Farm E

The upwind concentrations of bacteria mainly fell in the range of 10^1 to 10^2 cfu m^{-3} of air. This position, where possible, was away from any site activity. The exit refers to the fan or fans being monitored and gives the concentration of bacteria at this exit. The concentration at the exit fan ranged mainly between 10^3 to 10^6. At the 50m downwind sampling position there is a reduction of airborne bacteria ranging between 10^1 to 10^4 cfu m^{-3}. At the 100 to 200m positions it can be seen that in general the airborne concentrations of bacteria are close to the levels of the upwind positions. A good example was at farm C in the winter during a light period of day 1. The upwind concentration was $1.6x10^1$ cfu m^{-3} of air, the emission at the fan was $3.8x10^3$ cfu m^{-3}, at the 50 m position this concentration was reduced to $5.7x10^1$. At the 100, 200 and 400m positions the concentrations were $4.2x10^1$, $3.7x10^1$ and $1.3x10^1$ cfu m^{-3} of air respectively. In most cases beyond the 50m sampling position the airborne concentrations fell to what would be an expected level in an agricultural setting. However, there are some fluctuations at these positions which could be attributed to bioaerosol generating activities other than the fan that was monitored.

The concentrations of fungi upwind, downwind and at the poultry shed fan are given in Table 4.5. The upwind concentrations of fungi mainly fell in the range of 10 to 10^2 cfu m^{-3} (the exception being farm B during the summer). The concentrations at the exit fans ranged mainly between 10^2 to 10^3 cfu m^{-3} of air. At the 50 m sampling position concentrations were reduced by at least a factor of 10. At the 100 m sampling positions and beyond, the concentrations were in the main similar to the 50 m upwind position. The exception was at farm B during the summer period, where concentrations of 10^3 and 10^4 were detected. The higher concentrations, however, were measured both upwind and downwind outside, rather than inside the house and at the fan, suggesting that the aerosol concentrations were being increased from another source. A possibility was the harvesting of crops at upwind farms. However, at these positions, airborne concentrations were still at what would be an expected level in an agricultural setting.

The concentrations of endotoxins at the poultry shed fan are given in Table 4.6. The upwind and downwind concentrations were all extremely low or below the limit of detection. The highest airborne endotoxins were found at the fan and internally within the shed. Endotoxin concentrations ranged from 1 to 278 EU m^{-3}. Farm E during the summer had the highest concentration, 278 and 148 EU/m^3 during the summer for light and dark, respectively.

Table 4.4 Daily bacterial count [cfu m^{-3}] in the PM_{10} sample from the static Partisol samplers and the Anderson samplers (in brackets).

Farm Type	Farm ID	Winter/ Summer	Light/ Dark	Upwind 50m	Inside house	Exit	Downwind Up to			
							50m	100m	200m	400m
Broiler	B	Winter	Light	7 (159)	2810000	184968	76 (1414)	29 (371)	41 (196)	26 (293)
			Dark	74 (159)	125000	109083	194 (8225)	105 (2813)	64	30
		Summer	Light	169 (2362)	1186339	19851	6841 (11502)	6690 (12963)		
			Dark	610 (3592)	184634	68168	11401 (8533)	1871 (7730)		
	F	Winter	Light	9 (90)		1348509	362 (5889)	111 (12375)	144	118
			Dark	30 (392)		1276250	1822	814 (1147)	195	195
		Summer	Light	8 (709)		100329	371	34 (7627)	48 (15172)	12 (4162)
			Dark	83 (808)		39302	353	1714 (1746)	1994 (17056)	49 (5722)
Cage	A	Winter	Light	188 (701)	13122	42921	88	85 (375)	44 (207)	71 (279)
			Dark	189 (2771)	2769	70245	71	82 (989)	61 (671)	93 (636)
		Summer	Light							
			Dark							
	D	Winter	Light	86 (200)	24122	11770	1224	484 (10191)	1043 (6165)	
			Dark	23 (750)	3898	10131	34	18	23 (4934)	
		Summer	Light	55 (653)	5997	15403	49	125	(1433)	30
			Dark	20 (664)	9204	9811	8		(1873)	15
Free range	C	Winter	Light	16 (31)	19021	3762	57	42 (489)	37 (276)	13 (203)
			Dark	9 (1390)	2607	985	35	15 (1203)	51	18
		Summer	Light	19 (334)	9372	38891	21	18 (1549)		
			Dark	13 (518)	2894	2686	16	13 (110)		
	E	Winter	Light	20 (1619)	840	841	20	20 (1266)	20 (874)	20 (408)
			Dark	20	70	33636	20	20	20	20
		Summer	Light	54 (320)		227441	3616	224 (522)	106 (361)	
			Dark	32 (165)		226741	67	7	20	

Table 4.5 Daily fungi count [cfu m^{-3}] in the PM_{10} sample from the static partisol samplers and the Anderson samplers (in brackets).

Farm Type	Farm ID	Winter/ Summer	Light/ Dark	Upwind 50m	Inside house	Exit	Downwind up to			
							50m	100m	200m	400m
Broiler	B	Winter	Light	20 (450)	3023	356	9 (261)	29 (485)	51 (309)	20
			Dark	20 (410)	952	224	26 (707)	20 (719)	26	20
		Summer	Light	8719 (4853)	5868	222	7596 (4836)	8021 (3624)		
			Dark	198115 (3086)	3281	168	15040 (6294)	18157 (3655)		
	F	Winter	Light	19 (371)	19	5442	55 (2756)	51 (1021)	57	39
			Dark	30 (244)	30	2270	232 (1107)	47 (116)	97	49
		Summer	Light	6 (697)	6	3660	102 (1889)	30 (479)	36 (561)	20 (869)
			Dark	37 (530)	37	4605	273 (1680)	20 (521)	199 (1061)	98 (1177)
Cage	A	Winter	Light	25 (238)	60	91	21 (250)	31 (189)	43 (160)	41 (210)
			Dark	21 (270)	30	32	42 (536)	52 (583)	37 (564)	51 (461)
		Summer	Light							
			Dark							
	D	Winter	Light	490 (352)	334	20 ()	241 (1222)	20 (577)	251 (321)	
			Dark	13 (363)	100	275	10 (2208)	26	14 (497)	
		Summer	Light	188 (1717)		418	42 (3975)	224	(1851)	45
			Dark	20 (1604)		387	13 (3516)		(1360)	20
Free Range	C	Winter	Light	22 (110)	109	84	19 (183)	14 (121)	20 (142)	12 (140)
			Dark	9 (387)	39	20	20 (556)	19 (534)	16	15
		Summer	Light	30 (512)	416	20	20 (597)	15 (15032)		
			Dark	20 (189)	48	20	20 (5698)	20 (1929)		
	E	Winter	Light	175 (1140)		225	93 (618)	76 (480)	57 (447)	51 (360)
			Dark	45		164	85	57	61	30
		Summer	Light	620 (2905)		10105	495 (2784)	384 (2254)	367	
			Dark	28		160	14	14	38	

Table 4.6 Daily endotoxin levels in the PM_{10} sample from the static Partisol samplers maximum values for internal and emission points (extractor fan) EU m^{-3}.

Farm Type	Farm ID	Winter/ Summer	Light/ Dark	EU/m^3 Internal	EU/m^3 Exit
Broiler	B	Winter	Light	88	4
			Dark	4	4.2
		Summer	Light	1	1
			Dark	1	1
	F	Winter	Light	13.5	43.9
			Dark	28	50.9
		Summer	Light	3.25	5.5
			Dark	1.5	2
Cage	A	Winter	Light	23	6.8
			Dark	1.5	3.4
		Summer	Light		
			Dark		
	D	Winter	Light	1	11.7
			Dark	4.5	3.9
		Summer	Light	41.5	5.1
			Dark	17	2.5
Free Range	C	Winter	Light	70	10.6
			Dark	17	1.9
		Summer	Light	11	1.1
			Dark	1	1
	E	Winter	Light	21	13.3
			Dark	122	114.4
		Summer	Light	260	277.8
			Dark	80	147.8
Abatement	G	Winter	Light		448.5
			Dark		1275.7
		Summer	Light		29.54
			Dark		
	H	Winter	Light		
			Dark		
		Summer	Light	68.6	1.5
			Dark	27.9	4.8

4.2.4 Identification of predominant bacteria and fungi and prevalence of pathogenic bacteria.

The predominant bacteria and fungi isolated from the samples are listed in Table 4.7. The colonies throughout the sampling positions were very similar which made it difficult in some cases to distinguish between external and internal bacteria. The Genera of bacteria and fungi are typical of those found in agricultural situations.

The filter samples from the poultry farms were screened for *Salmonella* spp., *Campylobacter* spp and Verocytotoxin producing *E.coli* spp. All the filters from the farms in this study tested negative for *Salmonella* spp. and *Campylobacter* spp..

Only one farm had positive samples for verocytotoxin producing *E.coli.* Free range farm C was positive for three of the samples taken inside the poultry house. All three were taken in the light period for the birds. Two of the samples were taken in the same awake period on the first day from the PM_{10} background (upwind) sample and the PM_{10} sample from the extract fan, respectively. The remaining positive sample was from the second daylight period from the PM_{10} background sample. The samples were further analysed to determine whether the *E.coli* was the enterohemorrhagic 0157 strain. This proved negative.

Table 4.7 Predominant bacteria and fungi found on a subset from all locations and farms.

Bacteria	Fungi
Arthrobacter sp	*Acremonium sp*
Agromyces sp	*Aspergillus sp*
Acinetobacter sp	*Aspergillus fumigatus*
Bacillus simplex	*Aspergillus niger*
Bacillus macrides	*Aspergillus rosarium*
Bacillus sp	*Cladosporium sp*
Bacillus megaterium	*Eurotium sp*
Bacillus licheniforms	*Eurotium rubrum*
Brevibacterium sp	*Fusarium sp*
Brachybacterium sp	*Fusarium graminearium*
Corynebacterium	*Mucor sp*
Microbacterium sp	*Mucor plumbis*
Pseudomonas sp	*Penicillium sp*
Psychrobacteria faecalis	*Verticillium sp*
Plantibacter	*Yeast*
Psychrobacteria sp	
Proteobacterium	
Psychrobacter sp	
Rhizosphere soil bacterium	
Rothia sp	
Streptomyes sp	
Staphylococcus sp	

4.3 Assessment of the dust abatement measures and the impact on other pollutants

For Farm G, Figures 4.8(a-b) illustrate the changes in concentration and size distribution measured by the two APS instruments at Fan 3 (a) and the lee-side of the baffle (b), the latter plot has been corrected for dilution effects according to Eq. (1). The difference plot (c), highlights the greatest mass removal was consistent with the distribution of the particles leaving the shed, resulting not only in lower mass concentrations, but also a downward shift in the modal particle size by approximately 1 µm in this situation. This results in a total particle mass reduction of 70% as measured by the APS (up to D_p 20 µm). Over the entire measurement time period, there was a 15% reduction in PM_{10} concentrations, and $PM_{2.5}$ displayed an average decrease of 11%. APS data averaged over the time period used for the lowvol runs displayed a PM_{10} reduction of 22%, but a $P_{M2.5}$ abatement of 19%, in line with the to the 11% mentioned above.

The lowvol sampler measured an average dust reduction percentage of 9% and 26% for $PM_{2.5}$ and PM_{10} respectively. The overall increased dust reduction percentage for and PM_{10} (15-26%) compared to $PM_{2.5}$ (9-19%) is expected because the particle removal processes of impaction and interception occurring at the baffle have a greater effect on larger particles.

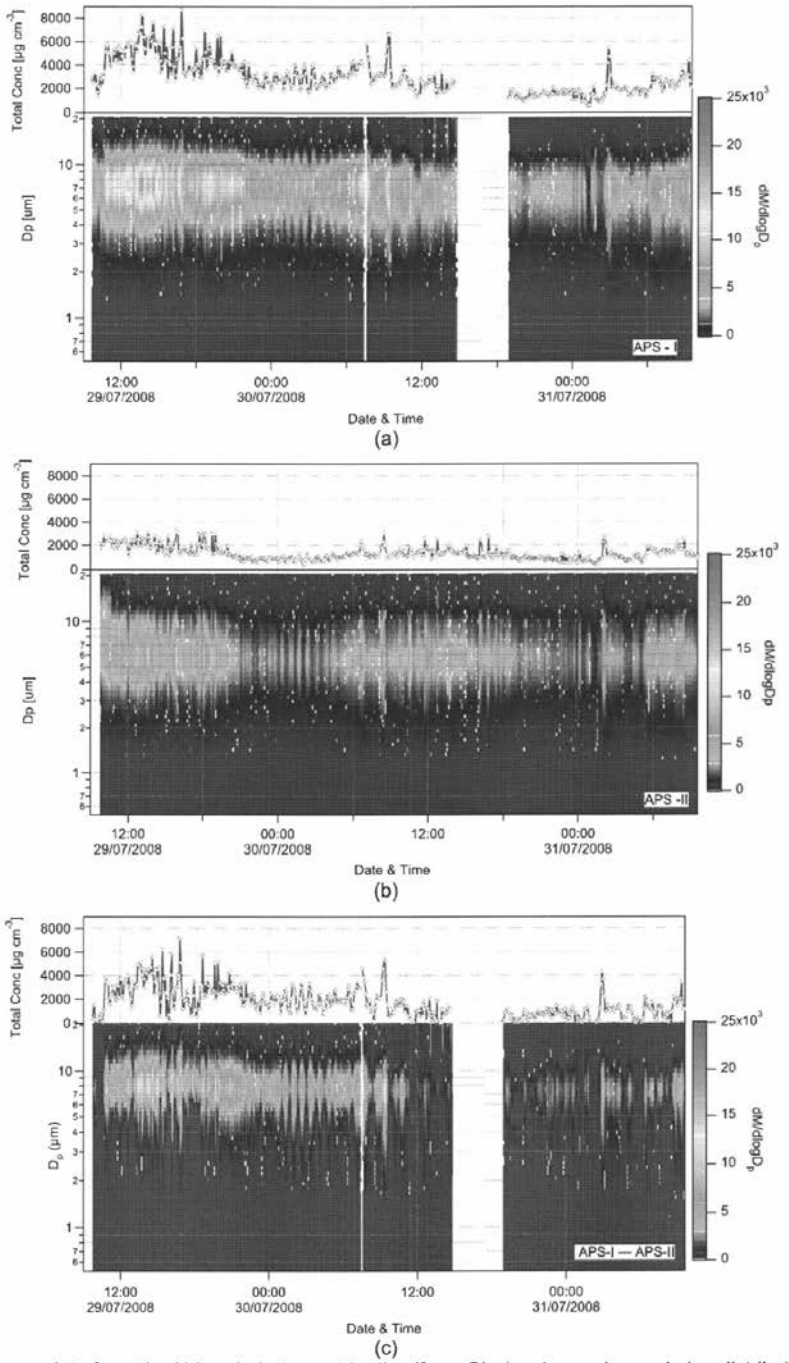


Figure 4.8 Image plots from the U-bend abatement broiler (farm G) showing series and size-distribution data (a) at the fan output, (b) at the lee-side of the baffle and (c) after subtracting b from a (emitted fraction). Data were remapped onto a 30 minute time base to allow the use of 30 minute ventilation rates, and results from the lee-side were normalised to SF_6 to remove concentration decreases due to dilution, using the equation from Section 3.4.

At Farm H the PM concentration was measured in the exhaust air upwind and downstream of the filter. The results (Figure 4.9) indicate that on average this system removes 69 +/-11% of PM10 and 36 +/-9% of PM2.5 particle fractions. The PM10 result compares favourably with the manufacturers stated claim of 70% "dust" removal and unpublished PM10 data showing 62% reduction in PM10 [BigDutchman, 2009]. During dark periods there is a slight drop in the percentage removal rates. The greater removal rate of the large particles again shifts the modal size distribution peak of the emitted particles towards smaller particles.

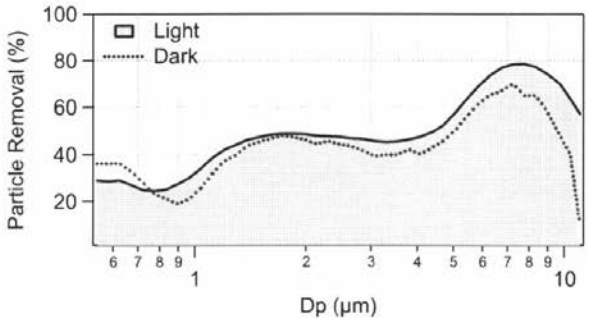


Figure 4.9 Percentage removal rates of particles by the abatement system according to particle size at broiler farm H and lighting regime.

The achieved reductions in dust and ammonia concentration for both abatement systems are summarised in Table 4.8. The results clearly indicate that neither the dry filter nor the deflector had any effect on the ammonia concentration and thus the ammonia emission. This was expected for the dry filter system, as the gaseous ammonia will pass straight through (analyser does not measure particulate ammonia). In the case of the dust trapping system a small reduction in ammonia concentration was expected, but the lack of water in the bath made this unlikely. The water bath had to be filled regularly (daily in summer, less frequently in winter) due to evaporation. As no automatic facilities for maintaining the water level were provided, the manual filling was omitted as it was not required in the IPPC permit.

Table 4.8 Efficiency of abatement measures on aerial pollutant emissions. The bacterial and fungal efficiencies are based on a log scale.

	Abatement method	
Efficiency (% ± sd)	Baffle (Farm G)	StuffNiX (Farm H)
$PM_{2.5}$	19	41 ±4
PM_{10}	22	64 ±6
Bacteria	16	1
Fungi	4	20
NH_3	0	0

The effect of the abatement techniques, the U-bend baffle (farm G) and StuffNiX filter, on the bacterial and fungi concentration is shown in Figures 4.10 and 4.11 respectively. Bacterial concentrations post abatement, were smaller than pre-abatement at both farms, but the efficiency is disappointingly low, compared to the reduction in both PM_{10} and $PM_{2.5}$. Concentrations were still considerably higher than the background measured 50m upwind. Concentrations at 50 m and 100m downwind (only measured at Farm G) had declined compared with the post abatement sample, but were still generally higher than background.

The trends in fungi counts were similar to bacterial concentrations, i.e., post abatement less than pre-abatement at both farms but greater than background. The abatement efficiency is again disappointingly low. At Farm G, downwind concentrations at 50 m and 100 m downwind were still higher than background, although less than post abatement. At Farm H, the downwind concentrations at 50 m were similar to the upwind background.

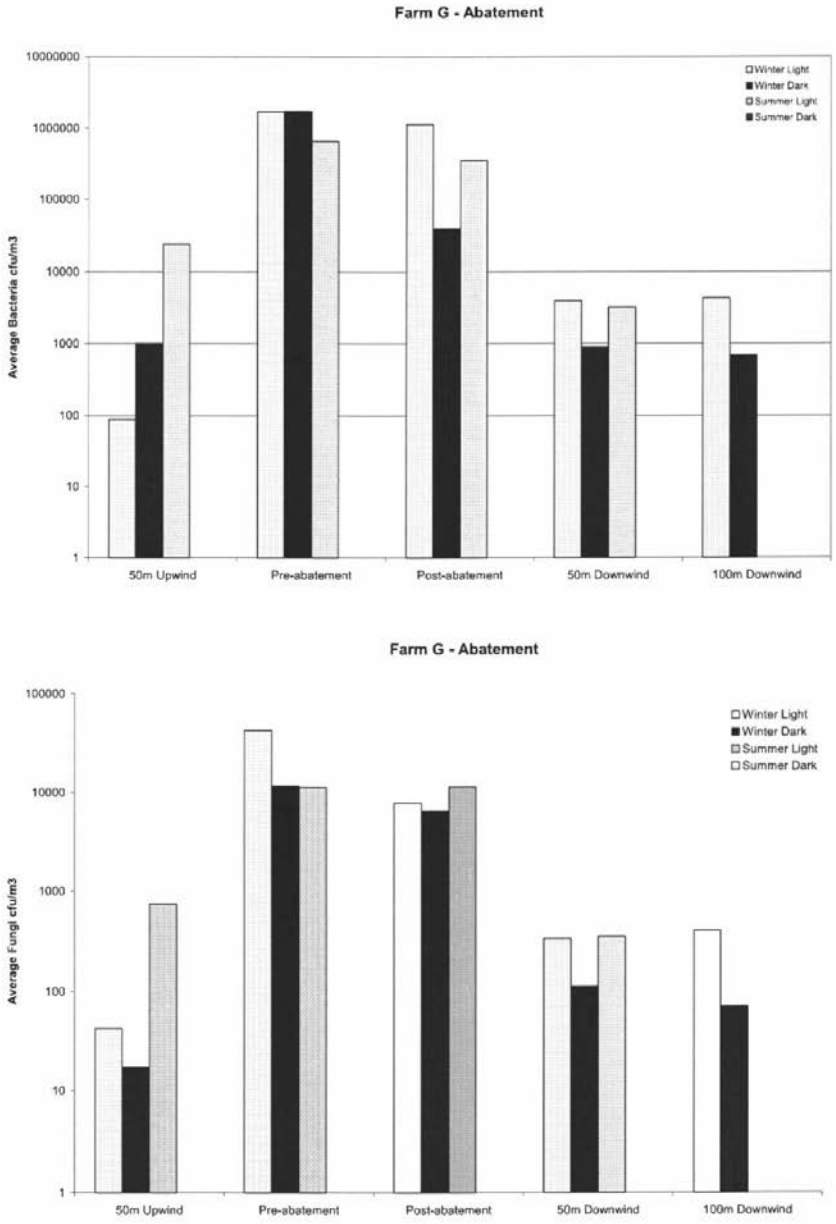


Figure 4.10 The impact of the dust abatement system, the air deflecting baffle, upon the bacterial concentrations (top) and fungi concentrations (bottom) up and downwind of the farm.

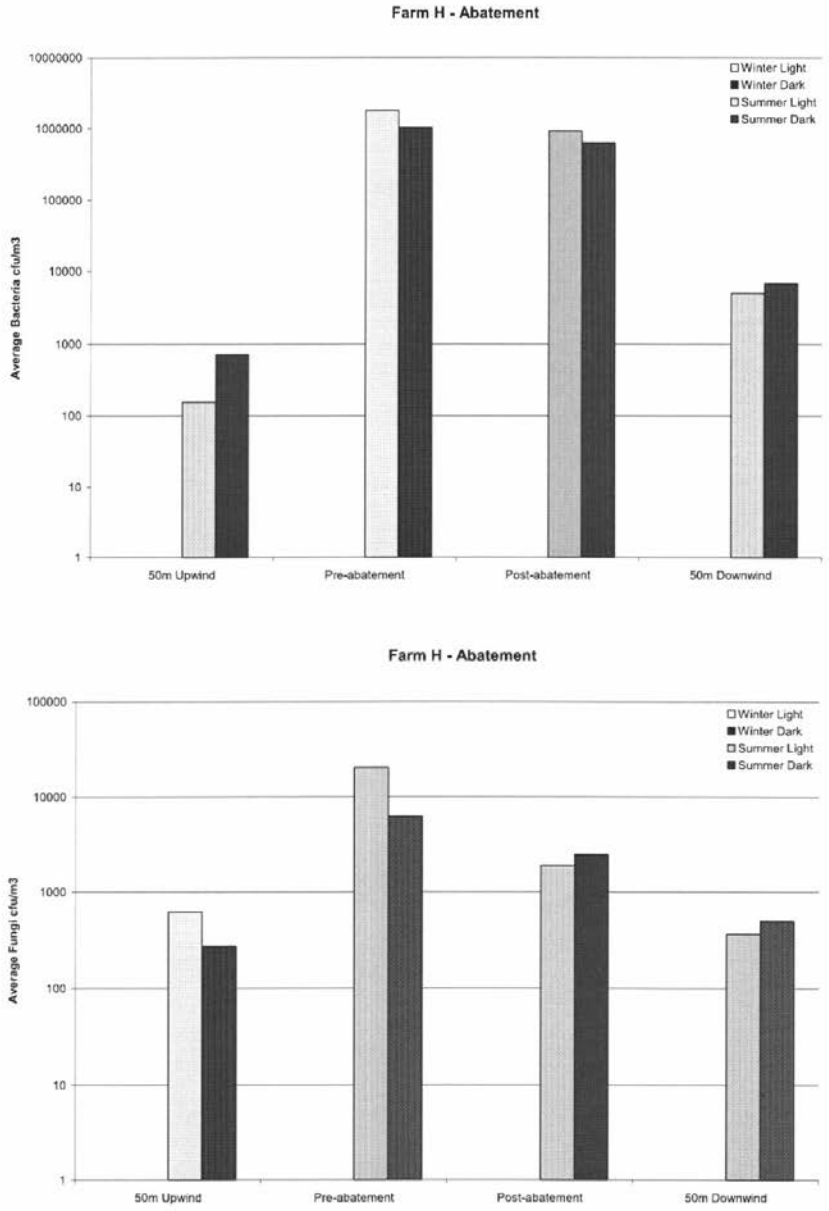


Figure 4.11 The impact of the dust filtering system, the StuffNix filter, upon the bacterial concentrations (top) and fungi concentrations (bottom) up and downwind of the farm.

4.4 Pollutant emission factors for poultry houses

To allow direct comparability with other installations and study results, emission factors (*EF*) are presented calculated per bird. During the course of our investigations, it was noted that PM_1 concentrations did not increase markedly inside the barn, and were instead related more to transport of regional air. Hence, it is not meaningful to calculate and present PM_1 emission factors. Only *EFs* for $PM_{2.5}$ and PM_{10} were calculated. Figure 4.12 presents our calculated emission factors segregated according to farm, season and diurnal period, error bars represent one σ between equivalent measurements (by different instruments).

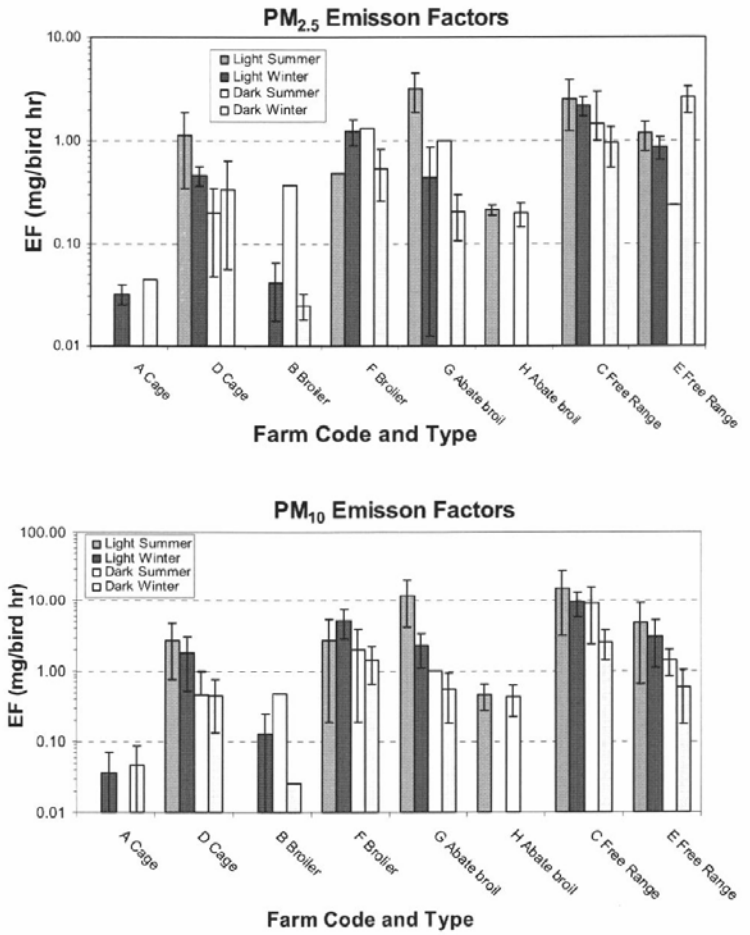


Figure 4.12 $PM_{2.5}$ and PM_{10} emission factors calculated from the combination of all relevant aerosol instrumentation and ventilation rates. Data are segregated according to farm, diurnal period, and season.

The results in Figure 4.12 display a wide range of *EF*s spanning two orders of magnitude, with the free-range layers displaying the maximum *EF* of 15.34 µg/(bird hr). The lowest *EF* of 0.02 µg/(bird hr) was measured at battery layer farm A. When calculated on a 'per farm' basis, the % ratio of $EF_{PM2.5}$ to EF_{PM10} (i.e. the contribution of $PM_{2.5}$ emissions to the emissions of PM_{10}) was greatest for battery birds (48%), compared with 21 and 30% for free-range layers and broilers respectively.

With a few exceptions (notably broiler farm B during dark summer periods and free-range layer farm E during dark winter periods), the sheds during light periods produced more particles than dark periods. Slight increases in summer *EF*s compared to winter time were observed, with the exception of broiler farm F, which displayed higher *EF*s in winter. This is consistent with the increased ventilation rate in summer.

Averaged data per farm type are given in Table 4.9, excluding broiler farm H where the abatement system prevented direct measurement of pre-abatement emission factors. Calculation of the PM_{10} *EF*s used measured upwind concentrations to calculate the net flux – and neglecting to do so resulted in an 18% *EF* increase, which gives a rough estimate of potential $EF_{PM2.5}$ discrepancies as upwind data were not collected for this size fraction.

Table 4.9 Averaged particulate and ammonia emission factors per farm type (mg/(bird hr) and g N/(kg lw day) respectively.

	Size Fraction	Layer Battery		Layer Free Range		Broiler	
		mean	σ	mean	σ	mean	σ
Light	$PM_{2.5}$	0.54	0.30	1.70	0.59	0.34	0.16
	PM_{10}	1.54	1.12	8.20	5.54	2.53	1.58
Dark	$PM_{2.5}$	0.20	0.22	1.33	0.90	0.16	0.04
	PM_{10}	0.32	0.30	3.40	2.20	0.55	0.53
	NH_3	0.18	0.28	0.78	0.48	0.18	0.30

The results of the crop-long study of emission factor changes with bird age confirm the assumption that larger birds generate higher emission factors (Figure 4.13). Particle size-distributions did not change significantly over the broiler chick growth period. Broiler measurements at operational farms presented in this study all took place during the final week of bird growth. Therefore, in order to compare with other studies which measure over the course of a crop, and to reduce error in UK wide when upscaling from broiler concentrations, the *EF*s for broilers in Table 4.9 have been multiplied by a correction ratio – comprising of the *EF* mean for the whole crop cycle, divided by the *EF* mean for the final week – this ratio has a value of 0.67 for PM_{10} and 0.36 for $PM_{2.5}$.

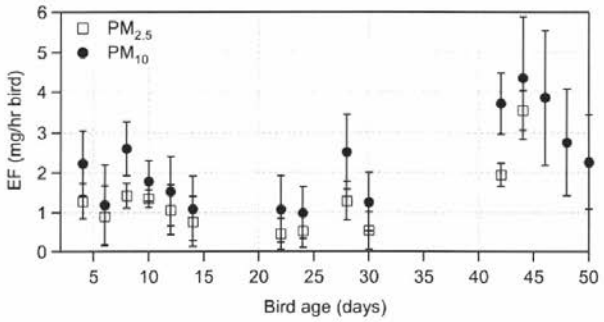


Figure 4.13 PM emission factors measured over the course of a crop cycle. Gaps are due to instrument malfunctioning. Error bars show one standard deviation of averaged measurements.

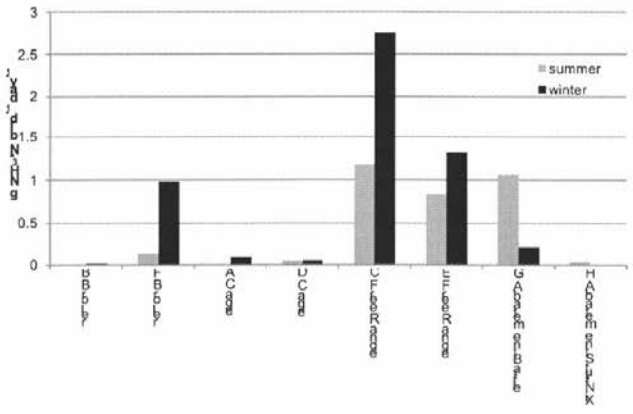


Figure 4.14 The ammonia emission factors for each farm in summer and winter calculated per bird place (g NH_3-N $bird^{-1}$ day^{-1})

The ammonia emissions were averaged over the measurement period and corrected for the number of birds (Figure 4.14 and Table 4.10). The ammonia emissions measured were 0.18, 0.78 and 0.18 g N (kg lw)$^{-1}$ d^{-1} for belt cleaned cages, free range layers and broilers on litter, respectively, 50% higher than the current emission factors in the UK ammonia inventory, i.e. 0.12, 0.3 and 0.12 g N (kg lw)$^{-1}$ d^{-1} (Misselbrook, 2006). However, most farms fall within the published range of values for their type used in the national inventory.

Notable exemptions were the free range unit C with high ammonia emissions in both summer and winter, due to the wet manure under the slats and as a result the high level of ammoniacal-N in the manure (Table 4.10). Equally, the emission from caged egg unit A was relatively high for same reason, despite the fact that the manure was removed weekly. However, the manure on the belts was 5 to 6 days old at the time of the measurements. Surprisingly, the emission from broilers was high on two occasions, namely for broiler unit G in the summer and farm F in the winter. The litter conditions were not the cause for the high ammonia emission from unit G with 71 % dry matter and low ammoniacal-N content. Hence the high emission is difficult to explain. For farm F the litter dry matter was relatively low and ammoniacal N high, thus potentially explaining the higher than expected emission.

The high emissions for the free range units compared to the other types are most likely due to the storage of all manure under the slatted area in the building. No attempts are made to keep this dry and the dry matter content is as a result low, hence the high emissions.

Ventilation rates were highly variable largely dependent on the ambient temperature at the time. The very low ventilation rate for broiler farm B in winter was due to faulty setting of the air inlet, causing a high under pressure (in excess of 50 pa), which negatively influenced the capacity of the fans used.

Table 4.10 Measured ammonia emission, ventilation and litter composition.

unit ID	Farm Type		NH_3-N	NH_3-N	Ventilation	DM	N total	NH_4-N
			g NH_3-N bird^{-1} day^{-1}	g NH_3-N kg.lw^{-1} day^{-1}	m^3 hour^{-1}	%	gN kg DM^{-1}	gN kg DM^{-1}
B	Broiler	winter	0.02	0.01	7,000	61.9	24	7.5
		summer	0.01	0.01	172,800	65.8	49.3	3.5
F	Broiler	winter	0.98	0.63	116,600	65.2	30.9	4.4
		summer	0.13	0.08	54,500	67.1	50.5	3.4
A	Cage	winter	0.10	0.05	60,600	26.6	43.1	23.1
		summer						
D	Cage	winter	0.05	0.02	76,700	27.8	54.4	3.3
		summer	0.05	0.02	73,500	31.6	73.7	3.9
C	Free Range	winter	2.75	1.49	74,600	26	62.9	36.5
		summer	1.19	0.61	52,300	29.1	44.5	23.4
E	Free Range	winter	1.32	0.63	74,300	42.7	39.2	8.3
		summer	0.83	0.41	83,100	40.7	22.4	8.6
G	Abatement Baffle	winter	0.22	0.15	34,500	66.8	33	3.4
		summer	1.07	0.68	310,900	70.9	46.3	1.8
H	Abatement StuffNiX	winter						
		summer	0.04	0.03	51,200	66.5	59.9	1.5

The emissions data for bacteria, fungi and endotoxin are given in Table 4.11. The results are expressed as culturable micro-organisms, referred to as colony forming units (cfu) or as Endotoxin units (EU) per kg of lw weight/day.

Table 4.11 Measured emissions of Bacteria, Fungi and Endotoxins, based on the PM_{10} samplers

Farm Type	Farm ID	Period	Bacteria		Fungi		Endotoxin	
			cfu hour^{-1}	cfu (kg lw)$^{-1}$ day^{-1}	cfu hour^{-1}	cfu (kg lw)$^{-1}$ day^{-1}	EU hour^{-1}	EU (kg lw)$^{-1}$ day^{-1}
Broiler	B	winter	$1.0x10^9$	$2.5x10^5$	$1.2x10^6$	$2.9x10^2$	$2.7x10^4$	6.6
	B	summer	$6.2x10^9$	$1.5x10^6$	$3.5x10^7$	$8.6x10^3$	<LOD	<LOD
Broiler	F	winter	$2.3x10^9$	$1.1x10^6$	$3.2x10^6$	$1.5x10^3$	$3.2x10^4$	$1.5x10^1$
	F	summer						
Layers Cage	A	winter	$1.3x10^9$	$4.0x10^5$	$2.5x10^6$	$7.9x10^2$	$1.2x10^5$	$3.7x10^1$
	A	summer						
Layers cage	D	winter	$7.0x10^8$	$4.8x10^5$	$9.3x10^6$	$6.3x10^3$	$6.0x10^5$	$4.1x10^2$
	D	summer	$5.6x10^8$	$4.5x10^5$	$2.1x10^7$	$1.7x10^4$	$6.7x10^5$	$5.3x10^2$
Layers Free Range	C	winter	$2.0x10^8$	$5.0x10^5$	$2.8x10^6$	$7.0x10^3$	$4.8 x10^5$	$1.2x10^3$
	C	summer	$5.9x10^8$	$1.5x10^6$	$1.9x10^4$	$4.9x10^1$	$1.9x10^4$	$4.x10^1$
Layers Free Range	E	winter	$8.6x10^8$	$6.7x10^5$	$8.5x10^6$	$6.7x10^3$	$6.6x10^5$	$5.1x10^2$
	E	summer	$9.5x10^9$	$7.4x10^6$	$2.8x10^7$	$2.2x10^4$	$1.6x10^7$	$1.3x10^4$

*<LOD = below limit of detection

The highest emission for bacteria was from a free range farm (E), with the highest overall emission from unit E during the summer at 9.5 $x10^9$ cfu hour^{-1}. However, the other farms had similar emissions ranging from 2.0 $x10^8$ to 6.2 $x10^9$ cfu hour^{-1}.

Free range farm E during the summer was also the highest emitter per kg of bird at v 7.4 $x10^6$ cfu (kg lw)$^{-1}$ day^{-1}. However, the other farms had very similar emissions on average no more than a factor 10 lower. Although bacterial emissions were expected to be slightly higher in summer compared to winter, in analogy to ammonia emissions, this was not always the case.

The highest emission for fungi was at broiler farm B during the summer, 3.5 $x10^7$ cfu hour^{-1}. Again, the other farms had similar emissions with all but one of the farms having emissions of 10^6 and 10^7 cfu hour^{-1}. Cage layer farm D during the summer was the highest emitter per kg of bird at 1.7 $x10^4$ cfu (kg lw)$^{-1}$ day^{-1}. The other farms had similar emissions with all but one farm having emissions of 10^3 and 10^4 cfu (kg lw)$^{-1}$ day^{-1}. As with the bacteria, summer emissions were on average higher than the winter emissions with the exception of free range farm C.

Endotoxin emissions were highest at free range farm E during the summer, 1.6 $x10^7$ EU hour^{-1}. The other farms had similar emissions of 10^4 and 10^5 EU hour^{-1}. Free range farm E during the summer was also the highest emitter per kg of bird at 1.3 $x10^4$ EU (kg lw)$^{-1}$ day^{-1}. The other farm emissions ranged from 7 to 1.2 $x10^3$ EU (kg lw)$^{-1}$ day^{-1}.

5 Discussion

5.1 Physical characteristics

By performing detailed particulate measurements on a number of UK poultry farms, this study aimed to improve understanding of (i) the physical and chemical characteristics of poultry related particles, (ii) their emission factors, and (iii) the ability of abatement systems to reduce concentrations. The measurement database to which to compare the results is limited. Several other studies have investigated the concentration of PM in poultry houses, which does not just affect PM emissions to the atmosphere but also occupational exposure of poultry workers. Table 5.1 puts our results into context with the literature.

The particle transmission of the respiratory system is not directly related to the metrics used for air quality assessment ($PM_{2.5}$ and PM_{10}). However, acknowledging the lack of current data for poultry installations, the EMEP/CORINAIR Emissions Inventory guidebook [UNECE/EMEP, 2007] assumes $PM_{2.5}$ and PM_{10} to be representative to inhalable dust (*ID*) and respirable dust (*RD*) respectively. The measurement of actual size-distributions during this study allows this assumption to be evaluated. Using transmission curves for RD and ID from this reference and APS data collected during this study, we derived ratios of PM_{10}/ID of 1.08 and $PM_{2.5}$/RD of 0.36. For comparison with published data, our measurements were converted to RD and ID using these factors and are compared in Table 5.1 with previously published measurements.

In general, our measurements display much lower concentrations of PM_{10} for all farm types whilst $PM_{2.5}$ measurements were of a broadly comparable magnitude. Differences between our ID concentrations and the two broiler farms studied by Schneider *et al.* [2005] may be explained by those researchers use of PM_{100} for ID and PM_4 for RD, which would clearly result in larger values compared to our measurements. In addition, the large difference in ID between the two farms studied by Schneider *et al.* [2005] may be attributed to the slatted floor present in the farm displaying the lowest concentrations, such a floor would prevent poultry material being available for re-suspension by moving birds. Only very slight seasonal differences are present in the Schneider *et al* [2005] data, generally with elevated concentrations in winter. Measurements by Lim *et al.* [2003] were made using a TEOM and provide a relatively comparable dataset to our measurements, but display slightly higher concentrations for PM_{10} and lower concentrations for $PM_{2.5}$. The comprehensive study by Takai *et al.* [1998] again has a wide range of concentrations for both ID and RD and are consistently higher for PM_{10} measurements than our data, but our $PM_{2.5}$ data are within their measured RD range. It is also worth noting that the Takai *et al.* [1998] data sampled from locations ranging from animal height to fan height (typically >2.0 m) – any average of these data may display higher values than measurements (such as ours) which were predominantly made at fan height due to increased gravitational settling of larger particles at lower heights. For the broiler farms, the data of Takai *et al.* [1998] also displayed higher concentrations than our measurements, with differences again more so for the PM_{10} concentrations rather than $PM_{2.5}$, by contrast our measurements are higher than the averages measured by Roumeliotis and Van Heyst [2007].

The general trend in all studies, including this one, is for broilers to display the largest dust concentrations, whilst battery layer farms display the least, but within each farm type group there are wide ranges of dust concentrations measured. This is unsurprising given the differences between shed sizes, ventilation methods, litter composition and management and lighting regimes employed across the farms featured in the aforementioned studies. A consistently lower result compared to other studies may simply be the product of better farm management practises within the past 10 years designed to limit exposure to dust and potentially reflects the fact that this study focussed on relatively modern installations.

At dark time bird activity decreases greatly (after an initial increase where birds have to find roosting spaces), but the ventilation rate also decreases, especially if dark time coincides with night-time. Both factors have opposing effects on PM concentrations inside the houses. The observed ~50% reduction in measured concentrations between light and dark periods suggests that the effect of bird activity was dominant. This will depend on the timing of dark periods (i.e. coincidence with actual night-time) and may be different in other climates with larger temperature differences between day and night. For example, Takai *et al.* [1998] did not observe a significant decrease in night-time particles at broiler farms at all, but this may be due to insufficient consideration of the light and dark times in their study: they classified night-time as the period between 18:00 – 06:00, which is unlikely to have coincided with lighting inside the shed.

The negligible seasonal influence on light period concentrations contrasted with an increase in winter dark time concentrations compared to dark period summer concentrations. This cannot be fully explained in terms of ventilation: during the summer and winter daytime periods the mean ventilation rates were 103,000 and 66,000 $m^3\ hr^{-1}$, respectively, and the in-shed concentrations were, on average, similar. Ventilation rates during the dark periods were 54,000 and 34,000 $m^3\ hr^{-1}$ for summer and winter, respectively, yet the average wintertime concentration during dark periods was 86% larger than the summertime average.

This pattern is similar to those mentioned by Takai [1998] and Roumeliotis and Van Heyst [2007], except in the latter study winter time light time concentrations are increased, probably due to decrease winter time ventilation in the Southern Canadian region where temperatures average a -10 °C minimum and differences between ambient temperatures are larger.

5.2 Chemical characteristics

The Q-AMS data indicated, along with the chemically resolved MOUDI data, that ammonium nitrate does not form in-situ either on other particles or as new particles during the residence time within the houses. Thus, dust abatement measures are not effective in reducing emissions of total reduced nitrogen (NH_x). Identification of the poultry sheds as sources of Ca^{2+}, Mg^{2+} and K^+ is indicative of these particles being produced from poultry feed or biological material as these are essential minerals for bird growth. The bulk of these compounds is not neutralised by the inorganic anions measured here (SO_4^{2-}, NO_3^-, Cl^-) and further chemical studies would be required to confirm PO_4^{3-} and organic compounds (such as CO_3^{2-}) as additional neutralising anions.

As with the inorganic chemicals, metal concentrations with significant concentrations within the poultry-dust size range were considered to be derived from inside the shed. Without further analysis it is not clear from which source the observed Al, As, Ba, Cu (light only), Cr, Mn, Rb, Sr and Ti originate. However, the large concentrations of Al recorded are dominated by particles >10µm, hinting at a mechanically derived source within the shed – e.g. conveyor feed units, this may also be the case for Ti.

The chemically resolved measurements (metals and major inorganic ions) only account for approximately 8% of measured aerosol mass, dominated by Ca^{2+}, K^+ and Mg^{2+}. Much of these base cations are not neutralised by the anions measured here, but probably by phosphate and, more importantly, organic anions, including carbonate. The bulk of remaining 92% is likely to be composed of coarse organic carbon, which was not measured during this study.

5.3 Bioaerosol emissions

This study has succeeded in providing data on bioaerosol emissions from a range of commercial poultry house types (broiler, egg laying, free range etc.) in summer and winter, and at different levels of bird activity (dark and light). Bioaerosol emission data have been calculated as hourly rates per poultry house and, taking into account the stock rate, as per kg bird weight per day. Overall, commercial poultry operations resulted in similar emission rates. This has provided a valuable source of data with which operators and regulators can assess the overall contributions of commercial poultry production to the airborne bioburden.

Bioaerosol emissions are within the range reported by Crook *et al* (2009). Seedorf *et al* (1998) reported emissions for bacteria, $2.3\ 10^8$ and $0.5\ 10^6$ $cfu.kglw^{-1}day^{-1}$ and fungi, $3\ 10^5$ and $4.8\ 10^6$ $cfu.kglw^{-1}day^{-1}$ for broilers and layers, respectively. The latter results for broilers are substantially higher than the emissions measured in this study, and might reflect the improved management of the modern broiler units of this study. The concentrations of fungi measured in this study was lower for both broilers and layers.

The poultry dust is known to be a significant source of bacterial, fungal and endotoxin contamination. A recent HSL study for HSE (Crook et al, 2008) has demonstrated that workers employed in handling poultry or in maintenance work are potentially exposed to high bioaerosol concentrations when working within poultry houses. Because poultry houses are vented to the atmosphere, a plume of bioaerosol will be generated at each ventilation point.

Bioaerosol samples taken inside poultry houses were of similar order of magnitude than those reported by Seedorf et al (1998) for layers and broilers in northern Europe (including the UK). Concentrations of airborne bacteria, fungi and endotoxin were generally greater during light periods than dark in correspondence with earlier findings of Seedorf *et al* (1998) and higher during winter than summer, with the notable exception of the free range houses. This reflected the likely levels of activity of the birds, with more bird movement during daylight hours creating greater disturbance of litter and associated contaminants. In summer, higher levels of ventilation for temperature control is likely to dilute the concentration more than in winter with similar generation rates of dust. Potentially, generation rates might be higher in the summer in litter based systems as the litter might be drier dryer and thus a bigger source when disturbed by the birds. However, although there were significant differences in litter dry matter values between systems (Table 4.10), the differences between summer and winter were small, hence the source strength should be similar based on this parameter.

Bioaerosol samples were taken downwind of poultry houses to compare with yields at the point of emission. Samples taken upwind provided background levels unaffected by the poultry houses as a point of comparison. The results showed that, while poultry dust emissions from houses significantly contributed to bioaerosol levels at short distances (50 m) from source, concentrations generally declined rapidly with distance from source. At the maximum distances from source where bioaerosol samples were taken downwind in this study (300 – 400 m), numbers were generally similar to upwind background. This may be expected because of the dispersion and dilution effect in open air. In some instances bioaerosol numbers were greater than upwind background, but this may have resulted from innate variation in environmental bioaerosol measurement or the influence of other bioaerosol sources in the vicinity, e.g., from other agricultural operations. Concentrations at 200-400 m from the building were generally low compared to previously published data (Table 5.2)

Abatement of dust emission is an important consideration for poultry farms. The baffle and StuffNiX abatement techniques succeeded in reducing bioaerosol emissions to a limited but variable degree. The disappointingly low efficiency is difficult to explain for the StuffNiX system, as both PM_{10} and $PM_{2.5}$ efficiencies were higher. The only reason might be that the bacteria and fungi are associated with an even lower size fraction that is not affected by the filter.

5.4 Emission factors

The opposite trend to that observed for the seasonal concentrations is observed in the seasonal emission factors, essentially for the same reason. Increased summer time ventilation compared with winter time increases the mass of particles ejected out of the shed because resuspended particles have less chance to re-settle inside the house if the residence time is shorter.

A recent study [Roumeliotis and Van Heyst, 2008] reviewed the available *EFs* for poultry farms globally which are presented in Table 5.3 along with the results of this study, together with some other more recent estimates. For the broiler farms, the PM_{10} *EF* data from Lacey et al. [2004] agrees well with our measurements, whilst those of Roumeliotis and Van Heyst (2008) are 50% lower, but still within one σ of our collective measurements. The measurements of Takai et al. [1998] are used in the latest edition of the EMEP/CORINAIR Emission Inventory Guidebook [UNECE/EMEP, 2007] as a basis for poultry *EFs* and are much larger than our converted ID *EFs*. It is not apparent at which stage in the broilers' life cycle the measurements from Takai et al. [1998] were conducted; if only mature birds were considered then their emission estimates would be elevated with respect to the entire crop cycle. Similarly to our PM_{10} and ID results, the $PM_{2.5}$ measurements from broiler farms are twice as high as the measurements of Roumeliotis and Van Heyst (2008) and the converted RD data are roughly half those measured by other researchers. At caged layer farms, Table 5.1 indicates PM_{10} measurements and equivalent ID results were towards the lower end of the published range of *EFs*, whilst our $PM_{2.5}$ and RD results were approximately twice as high as other reported values. There is a lack of measurements of PM emission factors from free-range layer farms in the literature. The results presented here indicate that free range emit more particles per bird than broilers. It should also be noted that no correction was made for the proportion of birds outside during measurements when calculating the *EF* in individual animal units; such a correction would further increase the emission factor for this type of installation. Behavioural research indicates that birds spend between 20-62% of their time outside [e.g. *Mahboub et al.*, 2004; *Shimmura et al.*, 2008].

An attempt was made to estimate the total annual emissions from UK poultry houses based on the results of this study (Table 5.4). The resulting estimate is significantly lower than the estimates presented by the UK National Emissions Inventory (NAEI) by factors of approximately 4 for both $PM_{2.5}$ and PM_{10}, reflecting the use of larger emission factors used in the NAEI calculations, especially for broilers. It should be noted that the study presented here focussed on modern poultry houses. Thus the difference in the estimates is likely to reflect, to some extent, the change from past to current technology.

Table 5.1: Comparison of in-house mean PM concentrations measured during this study with those in the literature.

Type of operation	Country	Study	Ventilation Type	House manure system	Concentrations ($\mu g/m^{-3}$)			
					ID	PM_{10}	RD	$PM_{2.5}$
Layer	Germany	[*Schneider et al.*, 2005]	Mechanically ventilated	Battery cage	3,550# W 3,330# S	-	1460& W 660& S	-
Layer	Germany	[*Schneider et al.*, 2005]	Mechanically ventilated	Battery cage	410# W 980# S	-	120& W 110& S	-
Layer	Denmark, England, Germany, Netherlands	[*Takai et al.*, 1998]	Various	Battery cage	750-1,640	-	30-230	-
Layer	USA	[*Lim et al.*, 2003]	Mechanically Ventilated	Battery cage	-	518 +/- 74	-	39 +/- 8
Layer	Germany	[*Thüringer Landesanstalt für Umwelt und Geologie*, 2008]	Various	Battery cage	-	700 W 600 S	-	-
Layer	UK	This Study	Mechanically Ventilated	Battery cage	297 W 228 S	321 W 246 S	303 W 292 S	108 W 104 S
Broiler	Denmark, England, Germany, Netherlands	[*Takai et al.*, 1998]	Various	Litter Floor	3,830–10,400	-	420-1140	-
Broiler	UK	This Study	Mechanically Ventilated	Litter Floor	741 W 991 S	800 W 1,070 S	1261 W 778 S	449 W 277 S
Broiler	Canada	[*Roumeliotis and Van Heyst*, 2007]	Mechanically Ventilated	Litter Floor	-	690	-	190
Layer	UK	This Study	Mechanically Ventilated	Free Range Litter Floor	655 W 419 S	707 W 452 S	427 S 295 S	152 W 105 S

PM_{100}; & PM4; S and W = Summer and Winter measurements respectively: ID = Inhalable dust and RD = Respirable dust. For measurements made during this study, PM_{10}/ID is estimated to be 1.08 and $PM_{2.5}$/ID is estimated to be 0.36.

Table 5.2: review of published data for Airborne bacteria and fungi (taken from Swan et al, 2003).

Location	Airborne fungi (cfu/m^3)	Airborne bacteria (cfu/m^3)	Reference
UK suburban	273 (0- 7,200)	79 (42 - 1,600)	Jones & Cookson, 1983
UK urban/industrial	1,200	500	Crook & Lacey, 1988
UK in homes	1,096 (28-35,000)		Hunter & Lea, 1994
Outdoor ambient, Paris	92 (3 - 675)		Mouilleseaux *et al*, 1994
France	2,999 - 9,841		Chaumont *et al*, 1990
Netherlands	941		Verhoeff *et al*, 1992
Netherlands	0 - 15,643		Beaumont *et al*, 1985
Austria rural	185	327	Kock *et al*, 1998
Scandinavia rural		99 (2 - 3,400)	Bovallius *et al*, 1978
Scandinavia urban		850 (100 - 4,000)	Bovallius *et al*, 1978
Finland	750		Nevalainen *et al*, 1994
US urban	930 (0 - >8,200)		Shelton *et al*, 2002
US rural	600	2,000	Folmsbee & Strevett, 1999
US urban	700	1,500	Folmsbee & Strevett, 1999
US rural	8,651 (80 - 94,000)	3,204 (160 - 17,600)	Hryhorczuk *et al*, 1996

Table 5.3 Comparison of *EF*s presented in this study with those in the literature – modified from Roumeliotis and Van Heyst [2008]

Type of operation	*Country*	*Study*	*Ventilation Type*	*House manure system*	*Emission Factor (mg/LU hr)*				
					ID	*PM_{10}*	*RD*	*$PM_{2.5}$*	*PM_1*
Broiler	Canada (Ontario)	[*Roumeliotis and Van Heyst*, 2007]	Mechanically ventilated	Litter floor	-	241.25 ± 7.9	-	50.8 ± 2.08	41.3 ±- 1.7
Broiler	Denmark, England, Germany, Netherlands	[*Takai et al.*, 1998]	Various	Litter floor	3570.8*	-	516.7*	-	-
Broiler	Netherlands	[*Van Der Hoek*, 2007]	Various	Litter floor	-	79.2	-	-	-
Broiler	United Kingdom	[*Wathes et al.*, 1997]	Various	Litter floor	-	-	600-850	-	-
Broiler	United States (TX)	[*Lacey et al.*, 2003]	Tunnel ventilated	Litter floor	-	537.5	-	-	-
Broiler	United Kingdom	This Study	Mechanically ventilated	Litter Floor	523 ± 331	565 ± 357	243 ± 103	87 ± 37	-
Layer	Denmark, England Germany, Netherlands	[*Takai et al.*, 1998]	Various	Battery cage	637.5*	-	79.2*	-	-
Layer	United Kingdom	[*Wathes et al.*, 1997]	Various	Battery cage	900 to 2200	-	75 to 258.3	-	-
Layer	United States (IN)	[*Lim et al.*, 2003]	Mechanically ventilated	Battery cage	-	625 ± 142	-	45.8 ± 12.5	-
Layer	The Netherlands	[*Van Der Hoek*, 2007]	Various	Cages belt system	-	9.6	-	-	-
Layer	United Kingdom	This Study	Mechanically ventilated	Battery Cage	163 ± 126	176 ± 136	199 ± 117	72 ± 42	-
Layer	United Kingdom	This Study	Mechanically ventilated	Free Range Litter floor	1343 ± 920	1450 ± 994	1053 ± 481	379 ± 173	-

ID = Inhalable Dust, RD= Respirable Dust *Forms the basis of the EEA (2006) *EF*s for poultry. For measurements made during this study, PM_{10}/ID is estimated to be 1.08 and $PM_{2.5}$/ID is estimated to be 0.36

Table 5.4 UK total Emissions from Poultry installations based on measured EFs

		EF* (kg/animal yr)			UK Total Emissions from Poultry Installations (t/yr)			
		Cage	Free Range	Broiler[Δ]	Cage	Free Range	Broiler	Totals
UK Total Numbers[†] (#)		15,846,036	10,108,678	108,753,182				
This study	$PM_{2.5}$	0.00252	0.01329	0.00187	40	134	203	**377**
	PM_{10}	0.00618	0.05084	0.01152	98	514	1,253	**1,865**
NAEI	$PM_{2.5}$							**1,620[$]**
	PM_{10}	0.0195		0.0588	506		6,395	**8,980[$]**
EMEP/CORINAIR	$PM_{2.5}$	0.0021		0.0068	55		740	**795**
	PM_{10}	0.017		0.052	441		5,655	**6,096**

*[†]Data for the total number of birds are derived from 2001 census data. [Δ]Broiler data are corrected for average bird weight over entire crop cycle. *Units were converted from this study using recorded numbers and weights of birds. [$]Also includes other poultry (e.g. turkeys)*

5.5 Abatement Efficiency

The dry filter abatement method used at broiler farm H was the most efficient way to remove particles, with reduced PM_{10} concentrations up to 70% observed. Despite the concrete apron at broiler farm G not being wet, the baffle system removed ~15-25% of measured particles. Nevertheless, in absolute figures, this house still had some of the largest emissions observed during this study, which may be more related to high ventilation rate and litter conditions. Neither abatement system had any effect on ammonia emissions. Integrating ammonia reduction techniques in the dry filter method will be very difficult, whereas it should be possible to integrate a simple wet scrubber to remove ammonia into the air deflection baffle method, potentially improving the dust removal efficiency. Since the effectiveness of the two abatement measures was only studied at one farm each, these results should be generalised with caution.

5.6 Assessment of the human health implications

Under EC Directive 2008/50/EC, there is a requirement for PM_{10} particle levels not to exceed a daily mean of 50 µg m^3 on more than 35 times per year, as measured gravimetrically in the UK Urban Air Network (http://www.airquality.co.uk/). The daily measurements are judged against a banding index in which bands 1 to 3 (0 to 49 µg PM_{10}/m^3) are rated low; 4 to 6 (50 to 74 PM_{10}/m^3) are rated moderate, 7 to 9 (75 to 99 PM_{10}/m^3) are rated high and band 10 (100+ PM_{10}/m^3) is rated very high (taken from AEA/Defra Report 'Air Pollution in the UK 2007' http://www.airquality.co.uk/annualreport/annualreport2007.php?d=tp#mid)

Based on this, the results from this study showed that daily PM_{10} levels, measured gravimetrically upwind of poultry houses to provide a background value, were mostly in the low rating. At 100+ metres downwind of poultry houses, PM_{10} values were similar to background. At 50 metres downwind, out of 21 sets of measurements only 4 would be rated moderate or high, one of these rating as very high. All of the higher rated values were associated with broiler houses.

The potential impact of long term exposure to raised levels of particulates include exacerbation of asthma attacks, increased bronchodilator use and increased hospital admissions due to asthma attacks; increased pneumonia, bronchitis and chronic obstructive pulmonary disease; increased respiratory symptoms in both the lower and upper respiratory tract; decreased lung function; increased incidences of rhinitis (Committee on the medical effects of air pollutants COMEAP Report 2009.
http://www.advisorybodies.doh.gov.uk/comeap/pdfs/finallongtermeffectsmort2009report.pdf)

The particulates data in this study provide a snapshot of conditions in the vicinity of poultry houses and should be viewed in this context. Although particulates were in some instances high or very high in close proximity downwind of broiler houses, there was no evidence that this would pose a significant burden to human health because it is unlikely that anyone will be in close enough proximity for long term exposure, and the data demonstrated that dilution effects dispersed particulates at greater distance.

The possible spread of infectious micro-organisms via dust emissions is of concern to the human population working and living in the vicinity of poultry installations. Some pathogens, in particular enteric bacteria, are likely to be present in faecal deposits from poultry and therefore may survive for some time outside the avian host and be present in litter. Dust emanating from litter may therefore harbour pathogens. In order to investigate this in the current study, polymerase chain reaction (PCR) molecular detection methods have been developed to test collected samples for the presence of DNA sequences of specific enteric pathogens likely to be present in poultry debris. The target bacteria chosen were *Salmonella* spp. *Campylobacter spp* and verocytotoxic *E coli*. *Salmonella* spp. are well recognised colonisers of poultry intestinal tract and cause gastro-intestinal infection in exposed humans. Verocytotoxin producing *E coli* bacteria are also present in animal faeces and are capable of causing abdominal pain and severe diarrhoea in humans. Some victims go on to suffer from bloody diarrhoea

(Haemorrhagic Colitis), Haemolytic Uraemic Syndrome and kidney failure, which can be fatal. *Campylobacter* spp. are bacteria that commonly infect a broad range of livestock species, pets and wild animals. In poultry they tend to multiply in large numbers in the hindgut, principally in the caecae. Campylobacters are a significant cause of enteritis in man. Infected poultry are a potential reservoir of this zoonosis.

Workers in poultry houses are potentially exposed to a range of allergens via inhalation, which has been described in detail in recent HSE guidance aimed at increasing awareness of employers in the industry to improve assessment and control of workers' exposure (http://www.hse.gov.uk/agriculture/poultry/index.htm). This exposure includes bioaerosols of bacteria, fungi and endotoxin, measured in this study.

Bioaerosol concentrations measured at vents from poultry houses were generally of a similar order of magnitude as bioaerosol concentrations measured in poultry houses (Crook *et al*, 2008). In that study, workers' exposure to airborne bacteria potentially exceeded one million cfu/m^3 air, endotoxin levels were as high as 38,000 EU/m^3, and airborne fungal concentrations up to 600,000 cfu/m^3. The concentrations of bacteria in poultry dust bioaerosols have been cited in previous published studies to range from 100,000 to 6 million cfu/m^3, with a mean value of 289,000 cfu/m^3, and fungi to range from 14,000 to 110 million cfu/m^3, with a median exposure of 440,000 cfu/m^3 (Radon *et al*, 2002). By comparison to other industries, these bacterial levels are similar to farmers harvesting grain, or workers handling compost or domestic waste at transfer stations, with fungal levels lower than in these industries (Swan *et al*, 2003).

Therefore, in close proximity to vents from poultry houses it could be argued that bioaerosol emissions represent a risk to human health through respiratory allergy comparable to that for workers inside the houses. However, as discussed previously, the dilution and dispersion of those bioaerosols means that within a relatively short distance (100 m) the risk to human health is significantly reduced. This is consistent with findings from another study that showed a reduction in dust and ammonia levels at 40 feet distance from poultry houses compared to 10 feet distance, although reduction in bacterial levels was less clear in that study (Davis and Morishita, 2005). Of the chosen specific enteric pathogens in our study, only verocytotoxic *E coli* could be isolated and only on one farm.

As a means of placing the bioaerosol emissions data from this study into context, they can be compared to typical bioaerosol concentrations measured in ambient air in urban and rural locations (Swan *et al*, 2003). Ambient background bioaerosol concentrations are typically 1,000 to 2,000 cfu/m^3 air, and airborne fungal and bacterial concentrations measured at points distant from poultry house vents were within the typical ambient range. It is therefore unlikely that people other than workers on commercial poultry farms will receive long term exposure to bioaerosols sufficient to trigger respiratory allergy or disease

6 Conclusions

This work represents one of the most comprehensive studies to quantify PM emissions from poultry housing to date, comparing a total of eight farms. Large variations between farm management practises, lighting regimes, litter conditions, and meteorology contributed to variability in emissions, even for the same type of farm. However, the measurements undertaken as part of this study were also able to identify differences in concentrations and emissions of particles between different farm types. The broiler installations were associated with the largest indoor air $PM_{2.5}$ and PM_{10} concentrations (655 µg m^{-3} and 2990 µg m^{-3}, respectively) and the highest bacterial fungal counts. Concentrations for particulate matter and bioaerosols were the lowest at battery farms. In general, indoor particle concentrations increased during winter time and light periods, reflecting ventilation rate and bird activity as the dominant influences. On the other hand, emission factors increased slightly during light-time in the summer months, due to the increase in ventilation rate.

Chemical speciation measurements indicated that (i) NH_4NO_4 was not forming within the shed, (ii) the dominant inorganic species sourced from poultry material are Ca^{2+}, K^+ and Mg^{2+}, and (iii) the key metals in the poultry sheds include Al, As, Ba, Cu (light only), Cr, Mn, Rb, Sr and Ti. We here derived, to our knowledge for the first time, poultry emission factors for aerosol chemical components (metals and major inorganic ions) and when compared against the NAEI suggest that between 0.1 – 4% (depending on compound) of the UK metal and inorganic ion emissions are derived from poultry house emissions.

Bioaerosol concentrations in the building represent a risk to poultry workers in terms of respiratory allergy or disease, but the levels emitted are sufficiently diluted over a short distance from the building so as not to pose a risk to those living in the vicinity of poultry operations. PM10 particulate levels were reduced to background levels by 100m downwind of even the highest emitting poultry houses, therefore are unlikely to pose a risk to those living in the vicinity of poultry operations.

Of the abatement systems tested, the baffle had a low efficacy for PM_{10} removal of 22%, whereas the dry filter (StuffNiX) method was far more effective at 67%. Neither affected the emission of ammonia.

7 Recommendations

- The updated emission factors for $PM_{2.5}$ and PM_{10} and ammonia need to be incorporated in the respective national inventories.
- Given the high variability of the measured $PM_{2.5}$ and PM_{10} emission factors in this work, a further program of measurements (less detailed) should be undertaken to improve the certainty of the data.
- Given the ban on conventional egg production cages from 2012 and consumer pressure a move towards more free range production and therefore higher $PM_{2.5}$ and PM_{10} emissions is to be expected. Therefore the potential for dust abatement at source and/or at point of emission should be investigated for free range management systems.
- The dust abatement system using a baffle was not operated as per the design, i.e. the water bath was empty. A return visit with the water bath operational could prove this method more efficient in removing dust (and ammonia) than found in this work.
- To enable effective abatement at source further measurements of dust and source composition should be considered.
- Other methods of dust abatement, developed and used in northern Europe should be included in a further study, as and when they are installed in poultry buildings in the UK.
- The risks of respiratory allergies and disease to poultry workers due to dust should (again) be communicated to the industry.

References

Aarnink, A.J.A. and Ellen, H.H. (2007) Processes and factors affecting dust emissions from livestock production. Presentation paper from "Dust Conference" *Animal Sciences Group*.

Aarnink, A.J.A., van Hattum, T., Hol, A. Zhao, Y. (2007) Reduction of fine dust emissions by combi-scrubber of Big Dutchman. *Animal Science Group. Report* 66.

Bailey W. Mitchell, B.W., Casey, R., Fairchild, B., Czarick M., Worley, J. (2003) Electrostatic Space Charge System for Air Quality Improvement in Broiler Production Houses., *2003 ASAE Annual Meeting* Paper number 034055

BigDutchman (2009), Abatement Measurements - personal communication, edited by R. Thomas.

Bottcher, R.W., Munilla, R.D., Keener K.M. (2000). Comparison of Odor Control Mechanisms for Wet Pad Scrubbing, Indoor Ozonation, Windbreak Walls, and Biofilters", (2000) *ASAE Annual International Meeting*, Milwaukee, Wisconsin, July 9 – 12.

Carpenter, G.A, and Fryer, J.T. (1990) Air filtration in a piggery: Filter design and dust mass balance. *Journal of Agricultural Engineering and Research* 46, 171-186.

Crook B, Easterbrook A, Stagg S. 2008. Exposure to dust and bioaerosols in poultry farming: Summary of observations and data. HSE Research Report RR655. Available at http://www.hse.gov.uk/research/rrhtm/rr655.htm

Davis M, Morishita TY (2005) Relative ammonia concentrations, dust concentrations, and presence of Salmonella species and Escherichia coli inside and outside commercial layer facilities. Avian Dis., 49, 30- 35.

DEFRA (2007) The Welfare of Farmed Animals (England) Regulations 2007 *Statutory Instrument 2078*. Office of Public Sector Information UK

Demmers, T.G.M., Phillips, V.R., Short, L.S., Burgess, L.R., Hoxey, R.P. And Wathes, C.M. (2001) Validation of ventilation rate measurement methods and the ammonia emission from naturally ventilated dairy and beef buildings in the United Kingdom. *Journal of Agricultural Engineering Research*, **79**,107-116.

Ekstrand, C., Algers, B. And Svendberg, J. (1997) Rearing conditions and footpad dermatitis in Swedish broiler chickens. *Preventative Veterinary Medicine* 31, 167 – 174.

Ellen, H. H.; Bottcher R. W.; von Wachenfelt E.; Takai H.. (2000) Dust levels and control methods in poultry houses. *Journal of Agricultural Safety and Health* 6, 275–282.

Fowler, D., et al. (2005), Changes in the atmospheric deposition of acidifying compounds in the UK between 1986 and 2001, *Environmental Pollution*, *137*(1), 15-25.

Gast, K. Bailey, Mitchell, W. and Holt, Peter S. (1999) Application of negative air ionisation for reducing experimental transmission of salmonella enteritidis to chicks. *Journal of Poultry Science* 78, 57-61.

Gooding C, Choudry P. V. 1999. Comparison of different primers for rapid detection of Salmonella using the polymerase chain reaction. Molecular and cellular probes. 13; 341 - 347.

Grime, J. (2004) Alternative Litter materials for growing poultry *North Carolina Poultry Industry Newsletter* Vol 1 Issue 2

Gustafsson, G., Von Wachenfelt, E. (2006). Airborne dust control measures for floor housing system for laying hens. *Agricultural Engineering International: the CIGR Journal.* Manuscript BC 05 018. Vol.VIII.

Habermann, B., Herfort, S,. Unrath, J. (2005) Dust Filtration through Applying Renewable Resource Material. *Landtechnik* 60, 3 page 154 - 155

Hahne, J. (2006), Assessment of Odour Reduction through Waste Air Treatment Systems *Landtechnik* 61, 1, pp. 38 - 39

Hoff, S. J., L. Dong, D. S. Bundy, H. Xin, J. Harmon, and X. Li. (1997). Odor removal using biomass filtering. *Proc. 5th Int. Symp. Livestock Environ. ASAE, St. Joseph, MI.* 101–108

Ikeguchi, A. (2002). Ultrasonic sprayer controlling dust in experimental poultry houses. *Journal Science. Research and Development.* 4,1–10.

Jacobson, L., J. Lorimor, J. Bicudo, and D. Schmidt. (2001) Emission control strategies for building sources. MidWest Plan Service. Iowa State University, Ames, IA. *Livestock and Poultry Environmental Stewardship Curriculum*. Lesson 41

Jayne, J. T., et al. (2000), Development of an aerosol mass spectrometer for size and composition analysis of submicron particles, *Aerosol Science and Technology*, *33*(1-2), 49-70.

Keguchi, Atsuo. (2002) Ultra sonic sprayer controlling dust in experimental poultry houses. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development.* Manuscript BC 01 002. Vol I. IV.

Kim, Ki Y., Ko, Han J., Kyung, Lee J., Park, Jae B. and Kim, Chi N. (2005) Temporal and spatial distributions of aerial contaminants in an enclosed pig building in winter. *Environmental Research* 99, 150-157

Kin, E., Mustajbegovic, E., Schachter, N., Kern, J., Rienzi, N., Goswami, S., Marom, Z. and Maayani, S. (1995) Respiratory function in poultry workers and pharmacologic characterization of poultry dust. *Environmental Zusesearch* 70,11-19.

Klimont, Z., and M. Amann (2002), European control strategy for fine particles: the potential role of agriculture, *Particulate Matter in and from Agriculture*, 29-35.

Lacey, R. E., et al. (2003), Particulate matter and ammonia emission factors for tunnel-ventilated broiler production houses in the Southern US, *Transactions of the Asae*, *46*(4), 1203-1214.

Lacey, R. E., et al. (2004), A review of literature concerning odors, ammonia, and dust from broiler production facilities: 1. Odor concentrations and emissions, *Journal of Applied Poultry Research*, *13*(3), 500-508.

Li, X., J. E. Owen, A. J. Murdoch, and C. C. Pearson. (1993). Respirable dust from animal feeds. In: *Proceedings of International Livestock Environment Symposium IV,* Warwick, England

Lim, T. T., et al. (2003), Air quality measurements at a laying hen house: Particulate matter concentrations and emissions, *Air Pollution from Agricultural Operations Iii, Proceedings*, 249-256.

Mahboub, H. D. H., et al. (2004), Outdoor use, tonic immobility, heterophil/lymphocyte ratio and feather condition in free-range laying hens of different genotype, *Br. Poult. Sci.*, *45*(6), 738-744.

Malone, G. W. (2008).Trees Kill odours and other emissions from poultry farms. *Science Centric.* August 2008

McGahan E., Kolominskas C., Bawden, K., Omerod, R. (2002) Strategies to reduce odour emissions from meat chicken farm. *Poultry Information Exchange Proceedings*

McMurry, P. H., et al. (2002), The relationship between mass and mobility for atmospheric particles: A new technique for measuring particle density, *Aerosol Science and Technology*, *36*(2), 227-238.

Mitchell, B.W., Buhr, R.J., Berrang, M.E., Bailey, J.S. and Coxt, N.A. (2002) Reducing airborne pathogens, dust and Salmonella transmission in experimental hatching cabinets using electrostatic space charge system. *Journal of Poultry Science* 81,49-55.

Okumura, J.I., and Hosoya M. (2000). Raised floor clean broiler house system without manpower in the house. CD Paper No. P15.20 in *Proc. XXII World's Poultry Congress*, Montreal, Canada.

Palmgren U, Strom G, Blomquist G, Malmberg P 1986 Collection of airborne micro-organisms on Nuclepore filters, estimation and analysis--CAMNEA method. J Appl Bacteriol. 61(5):401-6.

Patterson P. H. and Adrizal (2005) Management Strategies to Reduce Air Emissions: *Emphasis—Dust and Ammonia Poultry Science Association, Inc.*

Radon K, Danuser B, Iversen M, Monso E, Weber C, Hartung J, Donham Kj, Palmgren U, Nowak D. 2002. Air contaminants in different European farming environments. Ann Agric Environ Med 9, 41-48

Reynolds SJ, Milton DK, Heederik D, Thorne PS, Donham KJ, Croteau EA, Kelly KM, Douwes J, Lewis D, Whitmer M, Connaughton I, Koch S, Malmberg P, Larsson BM, Deddens J, Saraf A, Larsson L. 2005 Interlaboratory evaluation of endotoxin analyses in agricultural dusts--comparison of LAL assay and mass spectrometry. J Environ Monit. 7(12):1371-7.

Richardson, L.J., Mitchell, B.W., Wilson, J.L., Hofacre, C.L. (2003) Effect of an electrostatic space charge system on airborne dust and subsequent potential transmission of microorganisms to broiler breeder pullets by airborne dust. *Avian Diseases* 47, 128, 133

Rosentrater, K.A. (2003) Performance of an electrostatic dust collection system in swine facilities. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development* Manuscript BC 03 003. May.Roumeliotis, T. S., and B. J. Van Heyst (2007), Size fractionated particulate matter emissions from a broiler house in Southern Ontario, Canada, *Science of the Total Environment*, *383*(1-3), 174-182.

Roumeliotis, T. S., and B. J. Van Heyst (2008), Summary of Ammonia and Particulate Matter Emission Factors for Poultry Operations, *Journal of Applied Poultry Research*, *17*(2), 305-314.

Schneider, F., et al. (2005), Feinstaub im Stall, in *Planen und Bauen*, edited, pp. 38-39.

Seedorf, J., et al. (1998), Concentrations and emissions of airborne endotoxins and microorganisms in livestock buildings in Northern Europe, *Journal of Agricultural Engineering Research*, *70*(1), 97-109.

Seedorf, J. AND Hartung, J. 2000. Emission of airborne particulates from animal production. Available from: www.agriculture.de/acms1/conf6/ws4dust.htm

Shelton BG, Kirkland KH, Flanders WD, Morris GK. 2002 Profiles of airborne fungi in buildings and outdoor environments in the United States. Appl Environ Microbiol. Apr;68(4):1743-53

Shimmura, T., et al. (2008), Pecking behaviour of laying hens in single-tiered aviaries with and without outdoor area, *Br. Poult. Sci.*, *49*(4), 396-401.

Snell, H.G.J. Schwarz, A. (2003) Development of an efficient bioscrubber system for the reduction of emissions, *2003 ASAE Annual Meeting* Paper number 034053

Swan JRM, Kelsey A, Crook B, Gilbert EJ. Occupational and environmental exposure to bioaerosols from composts and potential health effects - A critical review of published data. HSE Research Report 130; pp35-37 http://www.hse.gov.uk/research/rrhtm/rr130.htm

Takai H.; Pedersen S.; Johnsen J. O.; Metz J. H. M.; Groot Koerkamp P. W. G.; G. H. Uenk;. Phillips V. R; Holden M. R.; Sneath R. W.; Short J. L.; White R. P.; Hartung J.; Seedorf J.; Schro der M.; Linkert K. H.; Wathes C. M. (1998) Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. *Journal of Agricultural Engineering and Research* 70, 59-77

Takai, H., et al. (1999), Ammonia contents in and emission from dust particles collected in livestock buildings, *Work Sciences in Sustainable Agriculture*, 189-193.

Thüringer Landesanstalt für Umwelt und Geologie (2008), Umweltdaten.

Tsai FC, Macher JM. 2005 Concentrations of airborne culturable bacteria in 100 large US office buildings from the

BASE study. Indoor Air.;15 Suppl 9:71-81

Tucker, S.A. and Walker, A.W., (1992) Hockburn in broilers. In Garnsworthy *et al* (eds) *Recent Advances in Animal Nutrition* Butterworth, Oxford UK, pp 33-50

Tymczyna, K. (2007). The effectiveness of various biofiltration substrates in removing bacteria, endotoxins and dust form ventilation system exhaust from a chicken hatchery. *Poultry Science* 86, 2095-2100.

Swan JRM, Gilbert EJ, Kelsey A, Crook B 2003. Occupational and environmental exposure to bioaerosols from composts and potential health effects - A critical review of published data. HSE Research Report 130. Available from http://www.hse.gov.uk/research/rrhtm/rr130.htm

UNECE/EMEP (2007), *EMEP/CORINAIR Emission Inventory Guidebook - 2007*, EEA.

Van Der Hoek, K. (2007), Particulate matter emissions from animal production in the Netherlands., paper presented at DustConf International Conference, Maastricht, the Netherlands.

Wathes, C. M., et al. (1997), Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses, *Br. Poult. Sci.*, *38*(1), 14-28.

Wathes, C. M., Holden M. R., Sneath R. W., White R. P., and Phillips V. R.. (1997). Concentrations and emissions rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust, endotoxin in UK broiler and layer houses. *British Poultry Science* 38, 14–28.

Wathes C. M; Phillips V. R; Holden M. R; Sneath R. W.; Short J. L.; White R. P.; Hartung J.; Seedorf J.; Schroder M.; Linkert K. H.; Pedersen S.; Takai H.; Johnsen J. O.; Groot Koerkamp P. W. G.; Uenk G. H.; Metz J. H. M.; Hinz T.; Caspary V.; Linke S. (1998) Emissions of Aerial Pollutants in Livestock Buildings in Northern Europe: Overview of a Multinational Project. *Journal of Agricultural Engineering and Research*. 70, 3-9

Wathes C.M. (2004) Air Hygiene. *Measuring and Auditing Broiler Welfare* (CABI - eds C.Weeks and A.Butterworth) page 128

Weijers, E. P., et al. (2000), Teom performance when sampling pure ammonium nitrate aerosol, *Journal of Aerosol Science*, *31*(Supplement 1), 25-26.

Williams, P. I. (2001), Construction and validation of a DMPS for aerosol characterisation, UMIST.

Wilson, S. Hughes, B.O. Appleby, M.C. & Smith, S.F. (1993) Perches and bone volume in laying hens. *Research in Veterinary Science* 54, 207

Whyte R.T. 1993 Aerial Pollutants and the Health of Poultry Farmers. Worlds Poultry Science Journal 49, 2, 139-156

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Working title: Ammonia emissions from poultry Installations
Journal: Atmospheric Environment / biosystems Engineering
Authors: Theo Demmers[b], Alexandra Saponja[b], Rick Thomas[a], Gavin J. Phillips[a], Chiara F. Di Marco[a], Alan G. McDonald[a], Jennifer Harris[a], Steven Bennett[c], Steven Stagg[c], Alison Bowry[c], Eiko Nemitz[a]
Submission: September 2009

Working title: Dust Emissions from Poultry Installations: I. Physical and Chemical Characterisation and Emission Factors
Journal: Atmospheric Environment
Authors: Rick Thomas[a], Gavin J. Phillips[a], Chiara F. Di Marco[a], Alan G. McDonald[a], Jennifer Harris[a], Alexandra Saponja[b], Steven Bennett[c], Steven Stagg[c], Alison Bowry[c], Theo Demmers[b], Eiko Nemitz[a]
Submission: September 2009

Working title: Dust Emissions from Poultry Installations: II Bio-aerosol composition and emissions
Journal: tbc (health and safety journal
Authors: Steven Stagg[c], Alison Bowry[c], Rick Thomas[a], Gavin J. Phillips[a], Chiara F. Di Marco[a], Alan G. McDonald[a], Jennifer Harris[a], Alexandra Saponja[b], Steven Bennett[c], Theo Demmers[b], Eiko Nemitz[a]
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