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Report 215

Measures to reduce fine dust emission from poultry houses: reduction from broiler houses by ionization

April 2009

ANIMAL SCIENCES GROUP
WAGENINGEN UR

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Colophon

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Abstract
In this study the effect was determined of a commercially available air ionization system on the reduction of airborne dust in a broiler house. Results showed a reduction, based on particle mass, of 36% and 10% for PM10 and PM2.5, respectively.

Keywords
Broilers, fine dust, ionization, dust reduction

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Title
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Samenvatting
In dit onderzoek is het effect van een ionisatie-systeem op de fijnstofemissie in een vleeskuikenstal bepaald. De resultaten laten een reductie zien, op basis van massa, van respectievelijk 36% en 10% voor PM10 en PM2,5.

Trefwoorden
Vleeskuikens, fijnstof, ionisatie, stofreductie

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Preface

Poultry housings with litter are a major contributor to fine dust emissions in The Netherlands. Recently it has become clear that part of the poultry producers are in need of mitigation options to comply with air quality thresholds for fine dust. Currently there are no mitigation options available. There is an urgent demand to develop cost-effective mitigation options, and to validate and quantify their performance in practice. In 2008 the Ministry of Agriculture, Nature and Food Quality has commissioned a research programme to the Animal Sciences Group of Wageningen UR to develop and validate a variety of mitigation measures that can be applied in different types of poultry housings. Within this framework, during 2008, research was carried out into an air ionization system in experimental broiler units. This report describes the main findings of the air ionization experiment. The contribution of all participants in this research is highly acknowledged, in particular Baumgartner Environics Inc. that installed the ionization equipment, the staff of the applied research centre 'Het Spelderholt', involved technicians and researchers of the Animal Sciences Group, Mrs. Cambra-López who carried out a significant part of the research as guest researcher from the Polytechnical University of Valencia, and members of the advisory committee of the Ministry. The results from this research will be used in further testing and validating the air ionization system on poultry farms in 2009.

Dr. Ir. N.W.M. Ogink
ASG Coordinator: Measures to reduce fine dust emissions from poultry housings
Animal Sciences Group of Wageningen UR

Summary

Current European and Dutch regulations require evaluation and quantification of dust emissions to verify compliance with EU thresholds and exposure limits. The standards for fine dust (PM10) and very fine dust (PM2.5) are exceeded in some parts of The Netherlands. Livestock houses in The Netherlands are responsible for approximately 20% of the total primary fine dust emission. Broilers raised on litter, in particular, are key contributors to atmospheric dust emissions. Besides the effect on outdoor air quality, studies have reported serious health effects of indoor dust on livestock farmers. From literature it is known that air ionization has high potential to reduce dust particle concentrations in livestock houses. The objective of this experiment was to determine the effect of a commercially available air ionization system on the reductions of airborne dust (PM10 and PM2.5), airborne micro-organisms, odour and NH_3 and on particle size distribution of dust in broiler houses. Furthermore we evaluated the performance of the system in terms of ion concentration, ozone production, ultra fine particle formation, and its influence on broiler performance.

The experiment was conducted in four identical rooms of the mechanically ventilated broiler house P1 of the applied research centre 'Het Spelderholt', in Lelystad. 2,676 broilers, a mixture of males and females, were placed in each room at a stocking density of 20 birds per m^2. Broilers were delivered at an age of 35 days and a target weight of 1,900-2,000 grams. As ionization system the "Electrostatic Particle Ionization" (EPI) system (Baumgartner Environics, Inc. USDA Patent number 6,126,722 U.S.A.) was used. The EPI system consisted of two rows of inline, negative DC ionization units running along the length of the rooms, composed of a discharge electrode (ion generator) and a grounded collection plate. These units were installed by the manufacturing company at a height of approximately 2.5 m above the litter. The discharge electrode was connected to a high voltage power supply to create a high density electron array (-30 kV DC), limited to a current of below 0.9 mA to assure safety. The emitted electrons generate negative charged ions. These ions charge circulating airborne particles, which are directed towards the grounded plates and are collected by electrostatic attraction on room surfaces or collector plates. The ionization system was randomly assigned to 2 of the 4 rooms, while the other two rooms served as control. The experiment was done during two rearing cycles (rounds). The following was measured or determined: ionization performance, ion concentrations, ozone concentration, ultra fine particle concentration, ventilation rates, PM10 and PM2.5 concentrations and emissions, personal dust exposure, particle counts in the different size ranges, emissions of airborne micro-organisms, odour and ammonia, animal production and exterior quality of the birds.

The installed ionization system worked correctly over the whole experiment. Voltage set to -30 kV did not vary along time, over the rearing cycle. Amperage readings showed some variation over the rearing cycle. For round 1, amperage showed a linear decrease in time. Amperage was set to 0.7 mA at the start of the experiment, and it gradually decreased along the rearing cycle, showing a minimum of about 0.4 mA at the end of the growing period. The cleaning of the plates in round 1, showed a slight effect on amperage, which tended to increase after cleaning. Dust deposited on room surfaces was evident after the first week of the rearing cycle. Visually, the difference between the treatment and control rooms became more evident through time, as concentrations of dust in the rooms increased. Treatment rooms showed a light yellow colour because of dust deposition on walls.

Mean ion concentrations, measured in round 2, were approximately 1,800 ions/cm^3, ranging from 220 to 6,400 ions/cm^3. Ion concentrations remained more or less constant along the whole experiment. Ion concentrations, however, were not uniformly distributed. As distance from the negative electrode increased, ion concentrations decreased, as also did the range of variation. Measured ozone concentrations were all below the detection limit of 0.01 ppm. Over the first days of the rearing cycle, however, ozone could be detected in the ionization rooms by the human nose, perceived as an intense smell of "clean bed sheets or fresh forest air". As ventilation rates increased along time, this smell could not be perceived anymore, after day 5. Ultra fine particle counts, in the range from 5 to 1100 nm, were on average 45% lower in ionization compared with control rooms.

Overall mean (SD) PM10 and PM2.5 concentrations were 1.01 (0.60) and 0.07 (0.05) mg/m^3, respectively. On average PM10 emissions for the control and ionization rooms were 33.4 and 20.1 g/year per bird in the first round and 16.1 and 11.7 g/year per bird in the second round. At logarithmic scale PM10 dust emissions decreased on average by 34% (s.e. 7%; $P<0.001$). The reduction was not influenced by the age of the birds. The overall measured mass reduction for PM10 emission was 36%. PM2.5 emissions for the control and ionization rooms were the same in the first round, on average 1.42 g/year per bird and 0.80 and 0.58 g/year per bird in the second round. At logarithmic scale PM2.5 dust emissions decreased on average by 33% (s.e. 11%; $P<0.05$). There was a tendency ($P<0.10$) for an effect of day number on PM2.5 reduction by the ionization system. Calculated reductions were 64, 23, 28, and 1% for day 16, 23, 30, and 33, respectively. Because dust emission

increases exponentially during the growing period, the overall measured mass reduction in PM2.5 emission was only 10%.

Continuous PM10 measurements showed a similar PM10 concentration pattern over the experiment. Concentrations of PM10 increased when lights were on, and decreased when lights were off. The cleaning of grounded collectors showed no statistically significant difference in PM10 concentrations in ionization rooms before and after cleaning, despite observed reductions of 10%, 24 h after cleaning. Personal sampling at human's breathing height showed that ionization rooms had a mean reduction of PM10 exposure of about 30%.

Particle counts per size range were generally higher in control compared with ionization rooms. Over the entire measured range (0.25 to 32 µm), two high reduction peaks were observed, one for particles between 0.58 and 1.0 µm, and one for particles between 5 and 30 µm, showing mean reduction percentages of approximately 40%. The middle particle size ranges (from 1.30 to 2.0 µm), and the smallest ranges (0.28 to 0.35 µm) showed the lowest mean reductions.

We did not find any difference in airborne micro-organisms, fungi, odour, and ammonia emissions between control and ionization treatments. Also, we did not find any effect of ionization on performance of the broilers (weight gain, mortality, feed conversion), on foot-pad lesions, on other parameters of external quality of the broilers, and on the quality of the bedding material.

From the results of this study we concluded the following:

- The tested ionization system (EPI system) is an efficient and appropriate dust reduction technique for broiler houses, with minimal maintenance and labour needs in case cleaning of the collection plates is mechanised.
- The ionization system reduces PM10 and PM2.5 concentrations and emissions (based on mass) in broiler houses by 36% and 10%, respectively.
- The ionization system seems to be more effective for particles in the coarse fractions (> 5 µm).
- The ionization system does not have a relevant effect on micro-organism, odour or ammonia emissions.
- The ionization system does not show any effect on broiler performance nor on litter quality.

It is recommended that the results of this study are validated and demonstrated on practical farms to facilitate implementation of ionization systems on broiler farms. While the system also has potential for layer housing, it is recommended that the ionization systems is tested in this environment, as well.

Samenvatting

De huidige Europese en Nederlandse regelgeving vereist een evaluatie en een kwantificering van fijnstofemissies om te bepalen of deze in overeenstemming zijn met de geldende EU normen. In sommige gebieden van Nederland worden de luchtkwaliteitsnormen voor fijnstof (PM10) en zeer fijnstof (PM2.5) overschreden. De veehouderij is in Nederland verantwoordelijk voor ca. 20% van de totale primaire fijnstofemissie. Vleeskuikenstallen stoten binnen de veehouderij het meeste fijnstof uit. Naast het effect op de buitenluchtkwaliteit, hebben studies tevens een duidelijk effect aangetoond van fijnstof op de gezondheid van de veehouder. Uit de literatuur is bekend dat ionisatie van de lucht potentie heeft om de stofconcentratie in stallen te verlagen. De doelstelling van dit onderzoek was om de effecten te bepalen van een ionisatiesysteem op de fijnstofconcentratie en fijnstofemissie (PM10 en PM2.5), op de emissies van micro-organismen, geur en ammoniak en op de deeltjesgrootteverdeling van het stof in een vleeskuikenstal. Verder werd in dit onderzoek het ionisatiesysteem zelf geëvalueerd ten aanzien van ionenconcentraties in de lucht, ozonproductie, de vorming van ultrafijne deeltjes, en het effect van dit systeem op de productieresultaten van de vleeskuikens.

Het onderzoek is uitgevoerd in vier identieke afdelingen van de mechanisch geventileerde stal P1 van praktijkcentrum Het Spelderholt in Lelystad. In elke afdeling werden 2676 vleeskuikens opgezet (hennen en hanen gemengd), met een dichtheid van 20 kuikens per m^2. Vleeskuikens werden afgeleverd op een leeftijd van 35 dagen met een streefgewicht van 1900–2000 gram. Als ionisatiesysteem werd het “Electrostatic Particle Ionization” (EPI) systeem geïnstalleerd (Baumgartner Environics, Inc. USDA Patent nummer 6,126,722 U.S.A.). Het EPI systeem bestond uit twee ionisatielijnen in de lengterichting van de afdeling met een groot aantal elektroden voor uitstoten van elektronen. Parallel aan deze ionisatielijnen liepen twee geaarde collectieplaten voor het stof. De lijnen hingen ca. 2,5 m boven de vloer. De ionisatielijn was gekoppeld aan een hoog voltage elektriciteitsunit om een hoogspanningsverschil te creëren (-30 kV gelijkstroom). De stroomsterkte had een maximum limiet van 0,9 mA, om de veiligheid te garanderen. De geëmitteerde elektronen genereerden negatief geladen ionen. Deze ionen zorgden voor een negatieve lading van de stofdeeltjes in de lucht. De geladen stofdeeltjes werden vervolgens aangetrokken door de geaarde platen en door de inrichting en de wanden van de stal. Het ionisatiesysteem werd aselect toegewezen aan 2 van de 4 afdelingen in de stal. De andere 2 afdelingen dienden als controle. Het experiment werd uitgevoerd gedurende 2 ronden vleeskuikens. Het volgende werd gemeten of bepaald: de werking van het ionisatiesysteem, de ionenconcentratie in de lucht, de ozonconcentratie, de concentratie ultrafijnstof, ventilatiedebiet, PM10 en PM2.5 concentraties en emissies, persoonlijke stofbelasting, aantallen deeltjes in de verschillende grootteklassen, emissies van micro-organismen, geur- en ammoniak, productieresultaten en kwaliteit van het exterieur van de kuikens.

Het geïnstalleerde ionisatiesysteem heeft zonder storingen gewerkt gedurende het gehele experiment. Het spanningsverschil van -30 kV varieerde weinig in de tijd. De stroomsterkte (ampère) liet wel enige variatie zien gedurende de groeiperiode van de kuikens. In ronde 1 nam de stroomsterkte geleidelijk af van 0,7 mA tot ca. 0,4 mA. Het schoonmaken van de collectieplaten in ronde 1 liet een lichte toename zien van de stroomsterkte. Na de eerste week werd een duidelijke toename zichtbaar van de hoeveelheid stof op verschillende oppervlakken in de afdeling. Het verschil met de controleafdeling werd meer en meer zichtbaar tijdens de groeiperiode bij een toename van de stofconcentratie in de afdeling. De ionisatieafdelingen hadden een lichtgele kleur vanwege de afzetting van stof op de wanden.

De gemiddelde ionenconcentratie, gemeten in ronde 2, was ongeveer 1800 ionen/cm^3, variërend van 220 tot 6400 ionen/cm^3. De ionenconcentratie bleef min of meer constant gedurende de ronde. De ionenconcentraties waren echter niet uniform verdeeld over de afdeling. Bij een toename van de afstand tot de ionisatielijn nam de ionenconcentratie af, evenals de grootte van de variatie. Ozon concentraties waren altijd beneden de detectielimiet van 0,01 ppm. Tijdens de eerste dagen van de ronde kon ozon echter worden geroken in de ionisatieafdelingen. Ozon heeft de geur van schone lakens of frisse boslucht. Bij een toename van de ventilatiehoeveelheid kon deze na dag 5 niet meer worden waargenomen. Ultrafijnstofconcentraties, in de range van 5 tot 1100 nm, waren gemiddeld 45% lager in de ionisatieafdelingen vergeleken met de controleafdelingen.

De PM10 en PM2.5 concentraties waren overall gemiddeld (sd) 1,01 (0,60) en 0,07 (0,05) mg/m^3. PM10 emissies waren gemiddeld voor de controle- en ionisatieafdelingen 33,4 en 20,1 g/jaar per vleeskuiken in de eerste ronde en 16,1 en 11,7 g/jaar per vleeskuiken in de tweede ronde. De PM10 emissie werd door het ionisatiesysteem gemiddeld, op logaritmische schaal, met 34% verlaagd (s.e. 7%; $P<0,001$). Deze reductie werd niet significant beïnvloed door de leeftijd van de vleeskuikens. De totaal gemeten massa reductie in PM10 emissie was 36%. PM2.5 emissies waren in de eerste ronde vergelijkbaar voor de controle- en ionisatieafdelingen, gemiddeld 1,42 g/jaar per vleeskuiken. In de tweede ronde was dit 0,80 en 0,58 g/jaar per vleeskuiken. Op

logaritmische schaal werd de PM2.5 emissie gemiddeld met 33% gereduceerd (s.e. 11%; P<0,05). Er was een tendens (P<0,10) dat deze reductie werd beïnvloed door de leeftijd van de vleeskuikens. De berekende reducties waren respectievelijk 64, 23, 28 en 1% voor dag 16, 23, 30 en 33. Omdat de stofemissie exponentieel toeneemt tijdens de groeiperiode, was de totale massareductie in PM2.5 emissie slechts 10%.

Continue PM10 metingen lieten een terugkerend concentratiepatroon zien over de meetperiode. PM10 concentraties stegen wanneer de lampen aangingen en daalden wanneer de lampen uitgingen. Het schoonmaken van de collectieplaten lieten geen effect zien op de PM10 concentratie in de stal, alhoewel 24 uur na schoonmaken de concentratie 10% lager was. Metingen van de persoonlijke stofbelasting lieten zien dat de ionisatieafdelingen een reductie gaven van de PM10 concentratie van ongeveer 30%.

Het aantal deeltjes per grootteklasse was in het algemeen hoger in de controleafdelingen dan in de ionisatieafdelingen. Over de gehele range (0,25 tot 32 µm) werden de hoogste reducties (ca. 40%) gevonden in de range van 0,58 tot 1,0 µm en in de range van 5 tot 30 µm. De laagste reducties werden gevonden in de ranges 0,28 tot 0,35 µm en 1,30 to 2,0 µm.

We vonden geen verschil in emissies van micro-organismen, schimmels, geur en ammoniak tussen de controle- en ionisatieafdelingen. Ook vonden we geen verschil in productie van de vleeskuikens (groei, sterfte, voerconversie), in het voorkomen van voetzoollaesies of andere parameters die de kwaliteit van het exterieur van vleeskuikens bepalen en in de kwaliteit van het strooisel.

Uit de resultaten kunnen we het volgende concluderen:
- Het geteste ionisatiesysteem (het EPI systeem) is een efficiënte en geschikte fijnstofreductietechniek voor vleeskuikenstallen. Het onderhoud en operationele kosten zijn minimaal, wanneer het schoonmaken van de collectieplaten wordt geautomatiseerd.
- Het ionisatiesysteem reduceert de PM10 en PM2.5 concentraties en emissies (op basis van massa) in vleeskuikenstallen gemiddeld met respectievelijk 36% en 10%.
- Het ionisatiesysteem lijkt effectiever te zijn voor deeltjes in de grove fracties (> 5 µm).
- Het ionisatiesysteem heeft geen effect op de emissies van micro-organismen, geur of ammoniak.
- Het ionisatiesysteem heeft geen effect op de productie van de vleeskuikens of op de strooiselkwaliteit.

We bevelen aan om de resultaten van deze studie te valideren en te demonstreren op praktijkbedrijven om de implementatie van dit systeem in de praktijk mogelijk te maken en te stimuleren. Aangezien dit systeem ook potentie heeft voor stallen met leghennen, wordt aanbevolen om het ionisatiesysteem ook in zo'n omgeving uit te testen.

Contents

1 Introduction

1.1 Context and scope

Current European regulations require evaluation and quantification of dust emissions to verify compliance with EU thresholds and exposure limits. EU has set an ambient air quality standard for maximum PM10 concentrations (particles with diameters equal or smaller than 10 µm) (EU, 1999). The maximum PM10 year round limit was set to 40 µg/m^3, and the maximum daily limit was set to 50 µg/m^3, with a maximum of 35 crossings per year. From 2010, an initial limit of 25 µg/m^3 has also been set for the finer fraction of particulate matter, PM2.5 (particles with diameters equal or smaller than 2.5 µm), by the Parliament and Council of the EU. From 2015, this figure will become a binding limit (European Parliament; The legislative Observatory, 2007).

The PM10 and PM2.5 standards are exceeded in some parts of The Netherlands (Anonymous, 2006). Livestock houses in The Netherlands are responsible for approximately 20% of the total primary fine dust emission (Chardon and Van der Hoek, 2002). Intensive poultry houses, together with pig houses normally reveal the highest concentrations of dust (Takai *et al.*, 1998). Furthermore, ammonia (NH_3) emitted from livestock facilities is a main precursor for formation of secondary aerosols in the atmosphere (Erisman and Schaap, 2004). Broilers raised on litter, in particular, are key contributors to atmospheric dust emissions (Takai *et al.*, 1998).

Dust is a potential hazard to the health and welfare of humans and animals. Studies have reported serious health effects of livestock farmers related to dust and increased incidence of respiratory problems such as chronic cough and/or phlegm, chronic bronchitis, allergic reactions and asthma-like symptoms (Zuskin *et al.*, 1995; Donham, 2000; Radon *et al.*, 2001). Animal's respiratory health may also be compromised by dust (Collins and Algers, 1986; Al Homidan *et al.*, 2003). Dust from livestock houses can cause respiratory affections to people living in the vicinity of the farms, as well (Lammel *et al.*, 2004; Seedorf, 2004). High concentrations of these particles can also threaten the environment (plants and other organisms), causing vegetation stress and ecosystem alteration (Grantz *et al.*, 2003). Atmospheric particles are relevant to climate change issues, such as cloud formation, radiative forcing, and it can contribute to atmospheric visibility impairment (IPCC, 2005).

It is necessary to identify appropriate control strategies and reduction technologies to aid policy-makers to establish adequate and accurate abatement measures to reduce dust emissions from livestock houses, and to protect the environment and ensure health and welfare of people and animals in and living near livestock houses. Research should focus on evaluation and development of efficient, practical and inexpensive cost-effective reduction technologies.

The Animal Sciences Group of Wageningen University and Research Centre is working on a framework of projects that aim to develop measures and techniques that reduce emissions of fine dust from poultry houses. The research projects are based on the overall 'Plan of action practical solutions for dust reduction from poultry houses' (Ogink and Aarnink, 2008) which is carried out for the Dutch Ministry of Agriculture, Nature and Food Quality. One of the reduction techniques under investigation is an air ionization system for livestock houses, which is considered a promising technique for reduction of PM emissions (Buisonjé and Aarnink, 2008).

1.2 Ionization in air cleaning

Air ionization has high potential to reduce dust particle concentration in a number of different applications (Bohgard and Eklund, 1998; Grabarczyk, 2001; Niu *et al.*, 2001; Lee *et al.*, 2004a; Grinshpun *et al.*, 2005). Ionization can also destruct, transform and remove potentially hazardous dust and volatile organic compounds, and it is claimed to have an improved performance compared to conventional technologies (filtration and adsorption), low energy costs, minimal bulk deposition of dust on undesired room surfaces, less hazardous reactants and by-products (Daniels, 2001), and the potential for possible associated health benefits (Krueger and Reed, 1976).

The use of ions in air cleaning can not only reduce the levels of dust, but also of odours and volatile organic compounds in indoor air by oxidation (Wu and Lee, 2004; Daniels, 2007). Ions also have bactericidal effects and can reduce airborne micro-organisms (Phillips *et al.*, 1964; Krueger and Reed, 1976; Grinshpun *et al.*, 2004; Lee *et al.*, 2004b; Fletcher *et al.*, 2007), and allergens (Goodman and Hughes, 2002; Dennis, 2003; Goodman and Hughes, 2004). On the other hand, some drawbacks of ionization are the emission of ozone during the ionization

process (Niu *et al.*, 2001; Chen and Davidson, 2003; Chen and Wang, 2005; Britigan *et al.*, 2006; Nagato *et al.*, 2006), and the generation of submicron aerosol particles (Hobbs *et al.*, 1990; Alshawa *et al.*, 2007). Some operational problems associated with ionization systems are the need of periodically cleaning of deposition surfaces and tubes (Tanaka and Zhang, 1996), as well as problems related to excessive electrostatic discharges and charging of objects (Grabarczyk, 2001; Grinshpun *et al.*, 2005), and the settling of precipitated dust on surfaces in the room (Grabarczyk, 2001).

1.3 Ionization in livestock houses

Ionization is a promising reduction technique showing high particle removal efficiencies of livestock dust, up to mass reduction levels above 90% (Mitchell *et al.*, 2004). Specific investigations have also been performed in swine buildings (Tanaka and Zhang, 1996; Rosentrater, 2003), cattle (Dolejs et al., 2006) and in rabbit production (Chiumenti and Guercini, 1990). Particle emissions less than 10 µm in diameter were reduced by 70 to 75% using a negative ionizer in cow barns (Dolejs *et al.*, 2006). Ionization has also been used to reduce airborne micro-organisms, showing important effects in killing aerial and surface microbial populations (Seo et al., 2001). The reduction in gases such as NH_3 has also been investigated (Mitchell *et al.*, 2004; Ritz *et al.*, 2006), however, results are ambiguous, with reductions ranging from 13 to 56%, and the working principle is still unclear.

Studies in poultry to reduce airborne dust and pathogens have been done in commercial hatching cabinets (Mitchell et al., 2002; Mitchell and Waltman, 2003), caged layers (Mitchell *et al.*, 2000), laying hens houses (Lyngtveit and Eduard, 1997), broiler breeder houses (Richardson *et al.*, 2003; Mitchell *et al.*, 2004), and in broiler production houses (Quarantelli *et al.*, 2000; Ritz *et al.*, 2006). Reductions in airborne dust fractions have been reported in the range from 40 to 90%. Only small reductions of dust levels in confinement buildings for laying hens, below 20%, and no statistically significant differences between the treated and control rooms were found by Lyngtveit and Eduard (1997).

Reductions of 96% in *Salmonella enterica serovar enteritidis* and other bacteria in different poultry houses have been observed (Holt *et al.*, 1999). A reduction percentage of 67% in airborne bacteria, and 30% in mould, in rabbit houses using ionization were measured (Chiumenti and Guercini, 1990). Airborne micro-organisms reductions usually exceeds dust reduction efficiencies, thus identifying dust reduction efficiency can be a good indicator of potential reduction levels of airborne pathogens (Mitchell and Waltman, 2003).

The influence of different parameters in dust reduction using ionization in livestock houses has also been evaluated. Special attention has been given to the effect of airflow (velocity and air exchange rate). Mitchell (1998) determined higher dust reductions when an air distributor (blower) was turned off, in a laboratory sealed chamber treated with an ionizer. Dust removal efficiencies have been shown to decrease as air circulation rates increase. An increase in the thickness of the accumulated dust on surfaces, reduces electrostatic voltage difference between the collection plates and dust layer, reducing settling efficiency to building surfaces (Tanaka and Zhang, 1996). Bundy (1984) also showed decreasing electrical field strength between the deposited layer of particles and the ground, as the layer of dust increased on the collection plates. This can be avoided by regularly cleaning the collection plates.

The differential effect of ionization on particles from different size ranges is still unclear. Most work has been carried out examining dust particles smaller than 10 µm. However, studying the effect of dust removal efficiency in different size ranges did not show significant differences for particles below 10 µm (Mitchell, 1998). Rosentrater (2003) showed better removal efficiencies for particles with diameters bigger than 3 µm. This type of work is important to identify whether differences exist in removal efficiency of ionization systems for particles within different size ranges.

Some problems in livestock houses using ionization have been identified, mainly related to voltage losses when lines of electrodes are too close, and the importance of weekly cleaning (Mitchell and Baumgartner, 2007). The electrostatic charge of buildings which could cause sparks or shocks to operators (Tanaka and Zhang, 1996) has also been raised as a matter of concern. Position of the apparatus in the livestock units, the use of ventilation and the appropriate voltage need further research, the cleaning of the accumulated dust surfaces also requires a refinement, although some investigations have shown good results with the incorporation of an automatic water manifold above the collector plates to rinse accumulated dust (Mitchell and Waltman, 2003), and the use of metal trays filled with water and liquid soap (Mitchell et al., 2002).

1.4 Aim of this study

An optimal design of ionization systems for use in livestock houses has not yet been fully developed (Rosentrater, 2004), although experimental results have shown good results of ionization to reduce dust concentration in livestock buildings (Chiumenti and Guercini, 1990; Tanaka and Zhang, 1996; Mitchell *et al.*, 2000; Rosentrater, 2003; Mitchell *et al.*, 2004; Dolejs *et al.*, 2006; Ritz *et al.*, 2006; Nicolai and Hofer, 2008). In fact, the performance of ionization systems for different applications still remains quite unpredictable, as well as its effects on particles in different size ranges, and on other hazardous pollutants such as NH_3 or airborne micro-organisms.

The objective of this experiment was to determine the effect of an air ionization system on the reductions of airborne dust (PM10 and PM2.5), airborne micro-organisms, odour and NH_3 and on particle size distributions in broiler houses. Furthermore we evaluated the performance of the system in terms of ion concentration, ozone production, ultra fine particle formation, and its influence on broiler performance.

2 Material and Methods

2.1 Materials

2.1.1 Housing

The experiment was conducted in four rooms of the mechanically ventilated broiler house P1, in the applied research centre 'Het Spelderholt' , in Lelystad, The Netherlands (Figure 1). All rooms were identical, measuring 8.3 m wide x 16.0 m long, with a volume of 500 m^3. Each room had four feeder lines, with seven feeders each (Minimax ,Roxell, Maldegem, Belgium), and 8 drinker lines, with a total of 180 drinking nipples (Ziggity, Middlebury, USA). Temperature was controlled with a central heating system with radiators on the sidewalls below the air inlet. Each room had three variable-speed ceiling ventilators (Ø 60 cm, max. cap. 7000 m^3/h per ventilator; Fancom B.V., Panningen, The Netherlands) under the roof-ridge. Each room had 12 air inlets (Tulderhof, Poppel, Belgium), six in each sidewall. As lighting system, high frequency fluorescent lamps were used in each room, controlled by a timer.

Figure 1 Broiler house P1 of the applied research centre Het Spelderholt, Lelystad, The Netherlands. Photograph at the left: outside view of the house. Photograph at the right: inside view of one room showing drinkers, feeders, radiators, air inlets and lights

2.1.2 Animals

A total of 21,408 Ross 308 broilers were used for the experiment, 10,704 broilers per round. One day-old birds from the hatchery Probroed en Soot, Groenlo, The Netherlands, were used. At the start of the rearing cycle, 2,676 broilers, a mixture of males and females, were placed in each room at a stocking density of 20 birds per m^2. Broilers were delivered to the processing plant at an age of 35 days, at a target weight of 1,900-2,000 grams. In broiler farms in practice broilers are often delivered in a first group of approximately 20-25% around day 35 followed by the rest of the broilers at the end of the production period (42-49 days). Because of the experiment our broilers were delivered in one group at day 35 applying the same end of cycle stocking density as is applied in poultry practice.

2.1.3 Ionization system

As ionization system the "Electrostatic Particle Ionization" (EPI) system (Baumgartner Environics, Inc., USDA Patent number 6,126,722 U.S.A.) was used. The EPI system consisted of two rows of inline, negative DC ionization units running along the length of the rooms, composed of a discharge electrode (ion generator) and a grounded collection electrode. These units were installed by the manufacturing company at a height of approximately 2.5 m above the litter. The discharge electrode consisted of a conductive tube with sharp pointed electrodes at 2.54 cm intervals, pointing towards the floor. This electrode was connected to a high voltage power supply to create a high density electron array (-30 kV DC), limited to a current of below 0.7 mA to assure safety. The emitted electrons generate negative charged ions. These ions charge circulating airborne particles,

which are directed towards the grounded plates and are collected by electrostatic attraction on room surfaces or collector plates. The collection and cleaning system was adapted between round 1 and round 2.

First round
The collection plates in round 1 consisted of two steel plates. These plates were located close to the discharge electrodes to maximize the electron output (Figure 2). The collection plates were manually shaken and cleaned every other day during the first rearing cycle.

Figure 2 Pictures of the EPI system installed in the treatment broiler house during round 1. Photograph on the left: steel collection plate and discharge electrode. Photograph on the right: view of one line of the ionization system, applied in a broiler room

Second round
The collection plates in round 2 consisted of the two steel plates used in round 1, plus four aluminium sheets. The sheets were evenly distributed along the width of the room (Figure 3). The two steel collection plates were manually shaken for cleaning, whereas the aluminium collection sheets had a mechanical cleaning system with brushes. Each aluminium collection sheet had a pair of brushes attached to it, which were pulled along the length of the sheet for wiping off the dust. The collected dust fell into a plastic bag, one for each sheet (Figure 3). Cleaning frequency increased in time, from once a week in the first week, to twice a week in week 2, to daily in week 5.

Figure 3 Pictures of the EPI system installed in the treatment broiler house during round 2. Photograph on the left: aluminium collection sheet showing brushes for cleaning and a plastic bag for dust collection. Photograph on the right: view of steel plates and aluminium sheets for collecting dust and discharge electrodes

2.2 Methods

2.2.1 Treatments

The effect of negative air ionization was studied in four identical broiler rooms. Two of these rooms were randomly assigned to the ionization treatment, while the other two rooms served as control. The experiment was done during two rearing cycles (rounds). Table 1 shows the distribution of these treatments in the rooms at the broiler house over both rounds in the experiment.

Table 1 Treatment distribution over the rooms, and over both rounds

Round	Dates	Room			
		1	2	3	4
1	15-05-2008 – 19-06-2008	Control	Ionization	Ionization	Control
2	21-08-2008 – 25-09-2008	Control	Ionization	Ionization	Control

2.2.2 Feed and water

Broilers had free access to feed and water during the whole experiment. For the first 10 days a pre-starter diet was given (2 mm crumbs), followed by a starter diet (composed of granules and 15% wheat, days 11-28) and a finisher diet (composed of granules and 30% wheat, days 29-35); the Superreeks diet of ForFarmers, Lochem, The Netherlands.

2.2.3 Lighting scheme

During the first two days, rooms were continuously lighted (24 h light : 0 h dark). During the rest of the rearing cycle, an intermittent light scheme was given of 8 h light and 4 h dark (07:45 – 15:45 (light); 15:45 – 19:45 (dark); 19:45 – 03:45 (light); 03:45 – 07:45 (dark)). Light intensity (20 lux) was the same for all rooms.

2.2.4 Climate control

Two days before the start of the experiment each room was heated to 33°C at day one of the rearing cycle. Temperature was then gradually decreased from 33°C at day one to 20°C at day 35 (Table 2).

Table 2 Temperature settings of the rooms at different birds' age

Setting	Age (days)	Target temperature (°C)
1	1	33
2	7	28
3	14	25
4	21	22
5	35	20
6	42	19

The three ventilators per room had a total maximum capacity of 21,000 m^3/h. Minimum ventilation level was set to 1 m^3 per kg of broiler weight. At minimum ventilation rate, only the middle ventilator was turned on. When the ventilation rate exceeded the maximum capacity of this ventilator, the other two were automatically turned on. In that case, all three ventilators were programmed to automatically work at equal ventilation rates.

2.2.5 Cleaning and bedding

In between the rounds the rooms were totally cleaned and disinfected. One day before the start of the experiment wood shavings were spread on the floor of each room at a density of 1 kg per m^2.

2.2.6 Vaccinations

Broilers were vaccinated following the 'Spelderholt vaccination protocol' of June 2004 (Table 3).

Table 3 Spelderholt vaccination protocol of June 2004

Age (days)	Disease	Vaccine	Administrated
1	I.B.	Poulvac IB primer D274/H120 (1 doses) or: Nobilis IB MA5 (1 doses)	In the hatchery
14	N.D.	Clone 30[1] (1 doses)	As a Spray
21 [2]	Gumboro	D78 (1 doses)	In the water (20 L/1000 doses)

[1] Alternative for the Clone 30: Avinew of Merial
[2] Age of vaccination depends on the Gumboro titre of the day-old chicks

2.2.7 Measurements and observations

During the experiment, the following measurements were done:

Ionization performance
Ionization system was supervised for correct functioning over the whole experiment. Electric potential difference (voltage) and current (amperage) were daily recorded. The performance of the ionizer was also assessed through measurement of concentrations of ions, ozone and ultra fine particles. After round 2, each dust bag was weighed to account for the total dust collected on the aluminium plates.

Ion concentrations were measured in each treatment room with an air ion counter (AlphaLab Inc., U.S.A.), with a range from 199.9 to 1000 positive or negative million ions per cm^3. The air ion counter samples air and deposits ions onto an internal collector plate. The number of elementary charges in the collector plate are measured by measuring the voltage on the grounded collector plate. Ion concentrations were measured weekly, in round 2, at five locations in each treatment room at a height of 1.75 m at different distances from the discharge electrode.

Ozone concentration was measured in each treatment room with ozone tubes (0.025-3.0 ppm, No. 182U, Kitagawa, Japan). Samples were taken inside each room, at a height of 1.5 m in the centre of the room. Sampling protocol was the same for round 1 and round 2. Two measurements per week were carried out during the first two weeks of the rearing cycle, because of the low-ventilation rates at that time. Weekly measurements followed. These tubes were selected for being the most sensitive, with a lower detection limit of 0.01 ppm. This lower detection limit could be reached by increasing the number of pump strokes.

Figure 4 The Condensation Particle Counter (CPC) placed on top of the CPC AIR Supply System

Ultra fine particle concentration was measured twice in round 1 (days 33 and 34), and three times in round 2 (days 19, 26 and 34), in all rooms during 30 minutes, using a Condensation Particle Counter (CPC, Series 5.400, Model number 5.403, with a CPC AIR Supply System, Grimm Aerosol Technik GmbH & Co., Ainring, Germany; Figure 4). Particle number concentrations with a higher cut-off diameter of 1100 nm, and a lower cut-off diameter

of 5 nm were measured. This instrument measured particle concentrations up to 10^7 particles per cm^3 with a time resolution of one second. The equipment was set to store one minute averages. From these, mean values for 30 min sampling were calculated.

PM2.5 and PM10 concentration measurements (cumulative, 24 h samples)
Dust particles smaller than 10 µm (PM10) and particles smaller than 2.5 µm (PM2.5) were sampled for 24 hours on days 16, 23, 30, and 33 (from 12:00 PM until 12:00 PM) in both rounds. The sampling position was close to the inlet of the ventilation shafts: at a horizontal distance of 0.5 m from the exhaust opening and at a vertical distance of 0.10 m underneath the exhaust opening. One PM10 sampler and one PM2.5 sampler were placed outside the broiler house to measure background dust concentrations.

Dust was collected on glass fibre filters (Ø 47 mm, type GF-3, Macherey-Nagel, Düren, Germany) after cyclonic separation with cyclone dust collectors (URG corp., Chapel Hill, USA). Separate cyclone dust collectors were used for PM10 and PM2.5 particles. Constant air flow pumps (Charlie HV, Ravebo Supply B.V., Brielle, The Netherlands) were used to sample the air, programmed at a flow rate of 1 m^3/h. During sampling, a moisture collection vessel for condensed water was located between the pump and the cyclone dust collector to protect the mechanics and electronics of the pump. Details of these equipments are shown in Figure 5.

The pumps are able to keep a constant air flow using a temperature sensor at the same position as the inlet of the cyclone dust collector. This flow can even be kept constant when the glass fibre filter is heavily loaded. The volume of air passing through the cyclone dust separator was transformed to standard conditions of 1 atmosphere and 0°C. The glass fibre filters were weighed before and after loading under standard conditions (temperature of 20°C ± 1 °C and 50% ± 5% humidity) with a Mettler balance (minimum reading 10 µg), according to NEN-EN 14907 (2005). The difference in the weight of the filter before and after loading and the standardized air flow were used to calculate PM10 and PM2.5 concentrations of the air sampled during 24 hours.

Figure 5 Sampling equipment for PM10 and PM2.5. Photograph upper left (from left to right): inlet, PM10 and PM2.5 cyclone collector and filter holder. Photograph upper right: adapted inlet for cyclone collectors. Photograph left bottom: the constant flow pump. Photograph right bottom: a constant flow pump connected to the condensed water collection vessel

PM10 concentration measurement (continuous, 24 h)
PM10 concentrations in the exhaust air were also continuously measured with a light scattering method on days 16, 23, 30, and 33 (from 12:00 PM until 12:00 PM) in both rounds. Measurements were carried out with one DustTrak per room (DustTrak TM Aerosol Monitor, model 8520, TSI Incorporated, Shoreview, USA; figure 6) placed in the same position as the PM10 and PM2.5 cyclones).

Personal dust exposure
The personal exposure to PM10 was determined three times in round 1 (day 25, 32 and 33) and two times in round 2 (day 25 and 32) in all rooms, using a DustTrak (DustTrak TM Aerosol Monitor, model 8520, TSI Incorporated, Shoreview, USA). The DustTrak was attached to the breast of one of the workers at a height of approximately 1.5 m (figure 6). Sampling was done during a routine inspection of seven minutes per room. PM10 concentrations (mg m^{-3}) were determined every second and one minute averages were logged in the DustTrak memory, resulting in seven values for each room.

Figure 6 Photo on the left: the DustTrak model 8520
Photograph on the right: measuring the personal exposure to PM10 with a DustTrak device

Particle size and particle counts
Particle number concentration and size distribution were measured twice in round 1 (days 33 and 34), and four times in round 2 (days 5, 19, 26 and 34) in all rooms, using an Optical Particle Counter (OPC, Model 1.109, Grimm Aerosol Technik GmbH & Co., Ainring, Germany; Figure 7). Size distribution of dust particles was determined for sizes between 0.25 and 32 µm (optical latex equivalent diameter), classified in 30 channel sizes. Sampling air flow rate was 1.2 L min^{-1}. Each room was sampled during 30 min. The equipment was set to a sampling interval of one minute. From these, mean values for 30 min sampling were calculated.

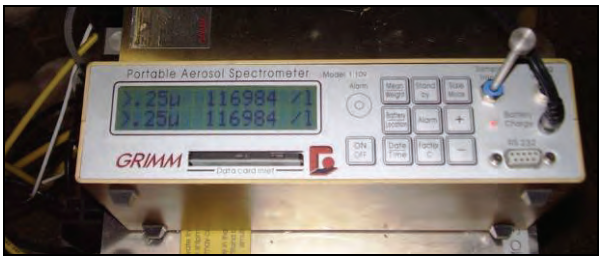

Figure 7 The Optical Particle Counter (OPC) for measuring particle size en counts

Airborne micro-organisms concentrations
The impingement method was used to determine total airborne bacteria, fungi and mould populations. Samples were taken weekly starting on the second week of the rearing cycle, at the same location as the dust sampling, at a 0.5 m horizontal distance from the exhaust opening and at a vertical distance of 0.10 m underneath the exhaust opening. Samples were taken during 15 minutes at days 15, 22, 29 and 32 both rounds.

Duplicate autoclaved all-glass impingers with 30-mm jet-to-bottom spacing (AGI-30, All Glass Impinger) were used. Sampled air was drawn into the impinger at a calibrated air flow rate of 12.5 L min^{-1}, using stationary pumps

(Charlie HV, Ravebo Supply B.V., Brielle, The Netherlands). Impingers were used with 20 ml of sterile 1% peptone-distilled water with 0.005% defoamer (Winterhalter Gastronom, GmbH). After sampling, the samples were transported to the laboratory under refrigeration. The final volume was measured and corrected for evaporation.

At the lab, serial 10-fold dilutions in 0.1% peptone distilled water were made, and 0.1 ml samples were plated onto duplicate plates: Plate Count Agar for total bacteria, and Oxotetracycline-Gentamicine-Glucose-Agar for total fungi and mould. Plates were then incubated at 30°C for 3 days for total bacteria and at 25°C for 3 to 5 days for total fungi and mould. Colony forming units (cfu) were counted on plates containing between 30 and 300 colonies (Thorne *et al.*, 1992). Airborne concentrations of total bacteria and total fungi and moulds were determined by multiplying the cfu by the dilution volume and divided by the volume plated (0.1 ml), and then calculated for the volume of sampled air, sampling time and flow rate.

Odour concentration
Two odour samples were taken per room, one on day 24, and one on day 31 of the rearing cycle, in both rounds. Two-hour samples were collected using the "lung principle". A new 40 L Nalophan odour sampling bag was placed in a rigid container. The bags had been flushed three times with compressed and odourless air. During sampling, air was removed from the container with a vacuum pump causing the bag to fill with a volume of air equal to the volume of air removed from the container. Flow rate of air entering the sample bag was 0.5 L/min. Odour samples were transported and stored according to CEN Standards 13725 (2003). Odour concentrations were determined by olfactometry within 24 hours after sampling (CEN Standard 13725, 2003).

Ammonia concentration
Ammonia concentrations were recorded continuously in the exhaust air with a NO_x monitor (model ML8840, Monitor Labs, Englewood, USA). Air was sampled in each room, at the exhaust of the middle ventilator which was working continuously, and transported through heated Teflon tubes to a convertor. In the convertor the ammonia present in the air was converted to nitrogen oxide (NO) at a temperature of 775 °C. From the convertor the air was transported trough heated tubes to the NO_x monitor where NO concentrations were measured and recorded continuously. Ammonia concentration of the inlet air from outside the house was recorded, as a background concentration following the same principle.

Ventilation rate and ammonia emission
The ventilation rate was measured with calibrated anemometers with the same diameter as the ventilation shafts, in each of the three ventilation shafts of each room. Hourly means were stored in a data logging system. To calculate emissions the concentration measured outdoor was subtracted from the concentration measured indoor and multiplied with the ventilation rate, following equation 1:

$$Emission = (C_{exhaust} - C_{inlet}) \times Q \qquad (1)$$

where: $C_{exhaust}$= concentration of specific pollutant i in the exhaust air of the room; C_{inlet}= concentration of specific pollutant i in the inlet of the room; Q= ventilation rate (m^3 h^{-1}).

Yearly emissions were calculated by multiplying the hourly data by 24 hours and 365 days and divided by the number of birds placed in the room at the start of the rearing period. For calculating the emissions per bird place the yearly emission per bird was corrected for 19% inoccupation of the rooms.

Humidity and temperature
The humidity and temperature of inlet and exhaust air were recorded continuously using combination sensors (Rotronic; ROTRONIC Instrument Corp., USA). Data was stored automatically in a database.

During both rounds the following observations were done:

Animal production
Broilers were weighed on arrival at the poultry house and before transport to the processing plant on day 35 to determine a start and end weight. All birds were weighed in groups. Furthermore, a sample of 100 broilers (50 male, 50 female) per room were weighed on day 21 and 34. The total feed intake was determined on day 21 and 35 and feed conversion ratios were calculated. Feed conversion ratios were corrected for mortality. Mortality numbers and weights per room where recorded each day.

Scoring of the exterior of the broilers
Before the transport to the processing plant the quality of the exterior of the broilers was scored in a random sample of 50 male and 50 female broilers. Animals were scored on the extent of breast dirtiness, breast irritations, scabby hips (thigh scratches) and hock burns as described in Van Harn (2008). Foot pad lesions were scored according to the protocol as described in Appendix 7.

Dry matter content of the bedding
Samples of the bedding in each room were taken on days 14, 28 and 35 to determine dry matter content. This was done as described in Appendix 8.

Scoring of bedding quality
The quality of the bedding was scored three times in each round (days 14, 28 and 35) as described in Appendix 8.

2.2.8 Statistical analysis

Fine dust emissions were statistically analyzed with the following model in Genstat (Genstat Committee, 2008):
LOG ($\underline{Y}_{ijk}$) = $\{\beta_{0i} + \underline{\varepsilon}_{0ij}\} + \{\beta_{1i} + \underline{\varepsilon}_{1ij}\}$ * t + $\underline{\varepsilon}_{ijk}$, where:

$\underline{Y}_{ijk}$	Response variable (PM10 and PM2.5 emissions) of measurement k for treatment i in room j
t	Day within growing period
β_{0i}	Intercept i (t=0, at the start of the growing period)
β_{1i}	Linear increasing trend in response during the growing period of treatment i
$\underline{\varepsilon}_{0ij} \sim N(0, \sigma^2_{0ij}), \varepsilon_{1ij} \sim N(0, \sigma^2_{1ij})$	Random room effect j of intercept and increasing trend, respectively, within treatment i
$\underline{\varepsilon}_{ijk} \sim N\left(0; \sum \tau_k, \phi_k\right)$	Random day effects correlated within room (Auto-regression), variances can differ between different measuring days

The statistical significant differences between control and ionization rooms for NH_3, micro-organisms, and odour emissions were determined over the entire experiment (both rearing cycles) with a two-tailed t-test (Genstat Committee, 2008). Differences with P values less than 0.05 were considered statistically significant, assuming equal variance of groups. The t-test was also applied to particle size data to compare treatment means per size range. Effect of cleaning and lightning schedule on PM10 concentrations in ionization rooms was analyzed by analysis of variance with a one-way ANOVA (Genstat Committee, 2008), with cleaning and lightning and its interaction as sources of variance. Effect of cleaning and lightning on PM10 concentrations reduction was analyzed in the same way including ionization and control as sources of variance. Results of birds' performance were statistically analyzed by one-way ANOVA (Genstat Committee, 2008), with ionization and control as sources of variance.

3 Results

3.1 Performance of ionization system

The installed ionization system worked correctly over the whole experiment. Voltage set to -30 kV did not vary along time, over the rearing cycle. Amperage readings showed some variation over the rearing cycle. For round 1, amperage showed a linear decrease in time. Amperage was set to 0.7 mA at the start of the experiment, and it gradually decreased along the rearing cycle, showing a minimum of about 0.4 mA on the last days (days 31 and 32). This decrease fits a linear regression, with a slope of -1%, showing a R^2 of approximately 0.79 (Figure 8).

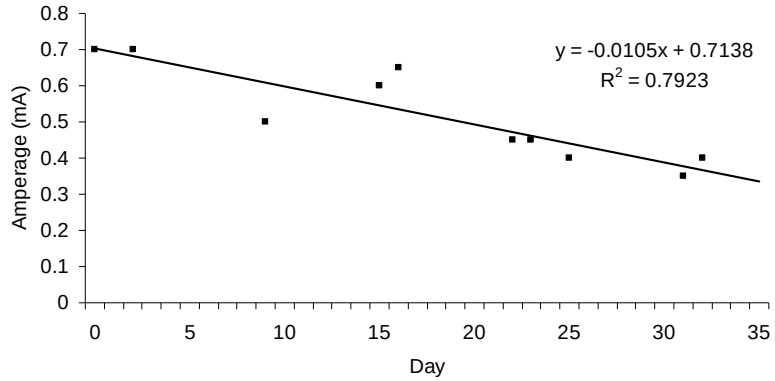

Figure 8 Linear decrease of amperage (mA) with time, for round 1

3.1.1 Ion concentration

Mean ion concentrations in round 2, for both ionization rooms were approximately 1,800 ions/cm^3, ranging from 220 to 6,400 ions/cm^3. Ion concentrations did not vary in time, and remained more or less constant along the whole experiment. In each room, however, ion concentrations were not uniformly distributed. In a transversal plane, ion concentrations showed peak values close to the negative electrodes (ion discharges). Maximum ion concentrations were observed at a distance of approximately 0.5 m from discharge electrodes, also showing a wide range of variation. As distance from the negative electrode increased, ion concentrations decreased, as also did the range of variation. Minimum values were recorded at the furthest distance from both discharge electrodes (1.5 m). This pattern was followed in both ionization rooms. Figure 9 illustrates this pattern.

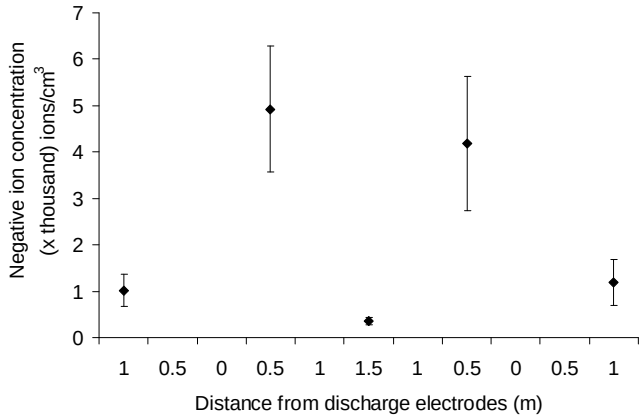

Figure 9 Mean ion concentrations (ions/cm^3) for ionization rooms and standard deviations at increasing distance from discharge electrodes. Distance (m) varies from 0 = location discharge electrode, to 1.5 m

3.1.2 Dust deposition and cleaning

The cleaning of the plates in round 1, showed a slight effect on amperage, which tended to increase after cleaning. In round 2, the amount of total dust collected and brushed off the aluminium plates at the end of the rearing cycle was 2,498 g of dust for room 2, and 2,399 g for room3.

Figure 10 Indication of dust deposition on room surfaces in the ionization rooms. Photograph on the left: metallic silo covered with dust (day 10, round 1). Photograph on the right: thickness of dust layer on plastic pipe (approximately 1 cm thick; day 34, round 1)

Dust deposited on room surfaces was evident after the first week of the rearing cycle. These surfaces were generally plastic or metallic (Figure 10). Visually, the difference between the treatment and control rooms became more evident through time, as concentrations of dust in the rooms increased. Treatment rooms showed a light yellow colour because of dust deposition on walls (Figure 11).

Figure 11 Visual aspect of treatment room on day 34, round 1. Photograph on the left: ionization room. Photograph on the right: control room

3.1.3 Ozone

Mean measured ozone concentrations in all rooms were below 0.01 ppm, for both rounds. Ozone concentrations remained below the lowest detection limit of the ozone tubes. Thus, no differences were found between ionization and control rooms. Over the first days of the rearing cycle, however, ozone could be detected in the ionization rooms, perceived as an intense smell of “clean bed sheets or fresh forest air”. As ventilation rates increased along time, after day 5, this smell was diluted and could not be perceived anymore.

3.1.4 Ultra fine particle concentration

Ultra fine particle counts measured with the Condensation Particle Counter in rounds 1 and round 2 showed particles in the range from 5 nm to 1100 nm were on average 45% lower in ionization compared with control rooms. Concentration of ultra fine particles decreased along time (table 4).

Table 4 Average ultrafine particle concentration (counts cm^{-3}) and standard deviations (SD) during the first and second rearing cycle in the control and ionization rooms

	Treatment	Ultra fine particles (counts cm^{-3})	SD	Reduction (%)
First rearing cycle				
Day 33	Control	23,295	5,671	76
	Ionization	5,684	2,141	
Day 34	Control	12,005	3,366	44
	Ionization	6,782	2,768	
Average	Control	16,569	7,113	62
	Ionization	6,308	2,553	
Second rearing cycle				
Day 19	Control	30,076	25,184	24
	Ionization	22,785	8,837	
Day 26	Control	11,176	8,005	74
	Ionization	2,871	341	
Day 34	Control	5,664	3,837	61
	Ionization	2,223	302	
Average	Control	15,394	18,341	40
	Ionization	9,216	10,797	
Total average	Control	15,641	16,618	45
	Ionization	8,563	9,654	

3.2 Dust concentrations and emissions (PM2.5 and PM10)

Mean (SD) PM10 concentrations and emissions over the experiment were 1.01 (0.60) mg/m^3 and 20.33 (16.58) g/year per bird, respectively. For PM2.5 these values were 0.07 (0.05) mg/m^3 and 1.05 (1.07) g/year per bird, respectively. Concentrations and emission of PM10 and PM2.5 increased with age of the birds. Ventilation rate data used for emission calculation, and environmental data (temperature and relative humidity) are shown in Appendix 1.

On average PM10 emissions for the control and ionization rooms were 33.4 and 20.1 g/year per bird in the first round and 16.1 and 11.7 g/year per bird in the second round. At logarithmic scale PM10 dust emissions decreased on average by 34% (s.e. 7%; $P<0.001$). The reduction was not influenced by the age of the birds (from day 16 onwards). On normal scale, giving the real total mass reduction in PM10 emission, a similar reduction of 36% was calculated. The measurements done in the first two weeks with the DustTraks showed higher reductions (on average 77%). PM2.5 emissions for the control and ionization rooms were the same in the first round, on average 1.42 g/year per bird and 0.80 and 0.58 g/year per bird in the second round. That no effect was measured in the first round was mainly caused by a negative reduction of -30% at day 33. At logarithmic scale PM2.5 dust emissions decreased on average by 33% (s.e. 11%; $P<0.05$). There was a tendency ($P<0.10$) for an effect of day number on PM2.5 reduction by the ionization system. Calculated reductions were 64, 23, 28, and 1% for day 16, 23, 30, and 33, respectively. Because dust emission increases exponentially during the growing period, the overall reduction, calculated at normal scale, was only 10%.

3.3 PM10 continuous measurements

Continuous PM10 measurements showed a similar PM10 concentration pattern over the experiment. Concentrations of PM10 increased when lights were on (light periods), and decreased when lights were off (dark periods). Figure 12 and Figure 13 show typical PM10 concentration pattern over 24 hour sampling, on day 9, round 1 (Figure 12), and on day 16, round 2 (Figure 13). Note two high and two low PM10 concentrations

periods. The light/dark pattern is observed in both days, in all rooms, with sharp PM10 spikes coinciding with lights on (07:45 and 19:45) (high PM10 concentration period) and PM10 decrease coinciding with lights off (15:45 and 03:45) (low PM10 concentration period). All data from DustTraks are gathered in Appendix 3.

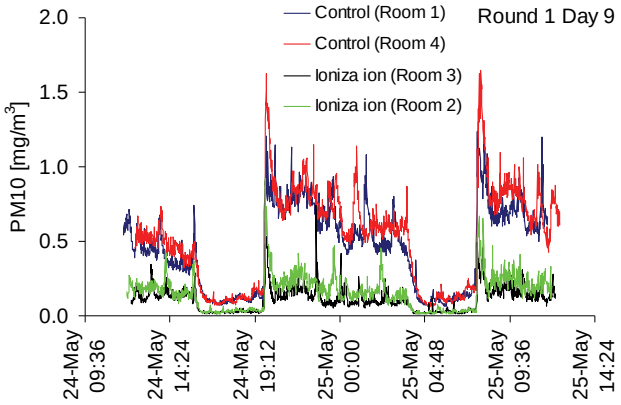

Figure 12 Continuous PM10 (mg/m^3) DustTrak values over 24 hours, on day 9 in round 1

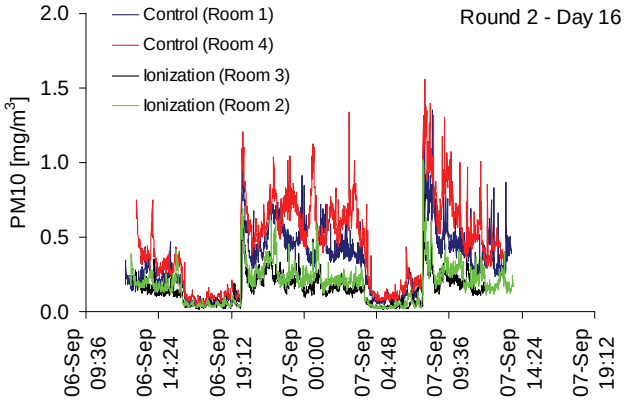

Figure 13 Continuous PM10 (mg/m^3) DustTrak values over 24 hours, on day 16 in round 2

Cleaning ionization grounded dust collectors showed a slight increase of 10% in PM10 concentration reduction during 24 h after cleaning compared with 24 h before cleaning, however, this difference was not statistically significant. Lightning schedule showed a significant effect on PM10 concentrations in ionization rooms (Figure 14).

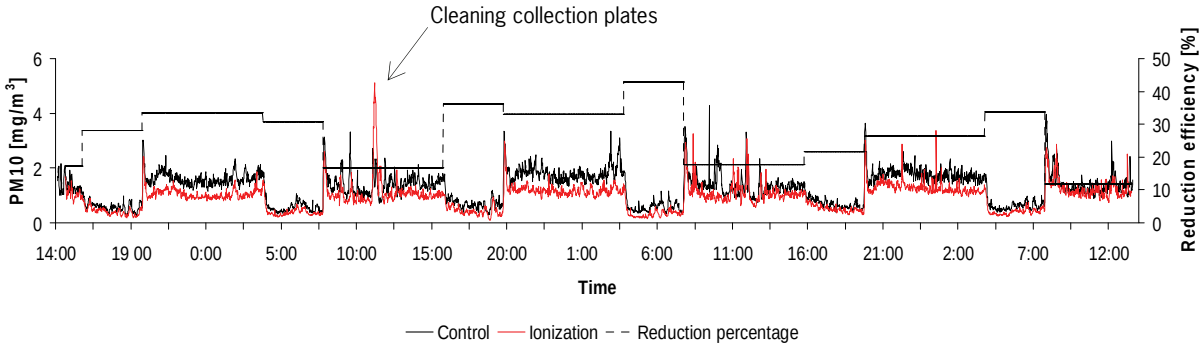

Figure 14 Continuous PM10 concentration (mg/m^3) monitoring over 72 hours, on day 31 to day 34 in round 1, before and after cleaning of the collection plates

3.4 Personal dust exposure (PM10)

Mean PM10 concentrations at human's breathing height, during personal sampling was generally lower in ionization rooms compared with control rooms. There was also an increase in PM10 concentration along time. Mean PM10 (SD) concentrations on day 25 were lower (for round 1; control: 0.99 (0.30) mg/m^3, ionization: 0.83 (0.25) mg/m^3, for round 2; control: 2.07 (0.64) mg/m^3, ionization: 1.49 (0.53) mg/m^3), than on day 32 (for round 1; control: 3.51 (0.77) mg/m^3, ionization: 2.40 (0.74) mg/m^3, for round 2; control: 2.65 (0.71) mg/m^3, ionization: 1.87 (0.50) mg/m^3).

Maximum PM10 values were higher in control rooms compared to ionization rooms, showing peak maximum values of 4.6 mg/m^3 in control, compared with 3.6 mg/m^3 in ionization, on day 32, for round 1. Peak maximum values were 2.4 mg/m^3 in control, compared with 2.0 mg/m^3 in ionization, on day 25, for round 2.

Ionization rooms showed an overall PM10 reduction to dust exposure of about 30%, expressed as the relative difference between the ionization and control rooms. This result is in concordance with our findings reported for 24 hour PM10 measurements using cyclones, where overall mean PM10 concentration reduction was 36%. Measured values over the rearing cycle, for round 1 and round 2 are shown in Figure 15. Estimated PM10 dust exposure reduction expressed as percentage difference of control and ionization rooms is shown in Figure 16.

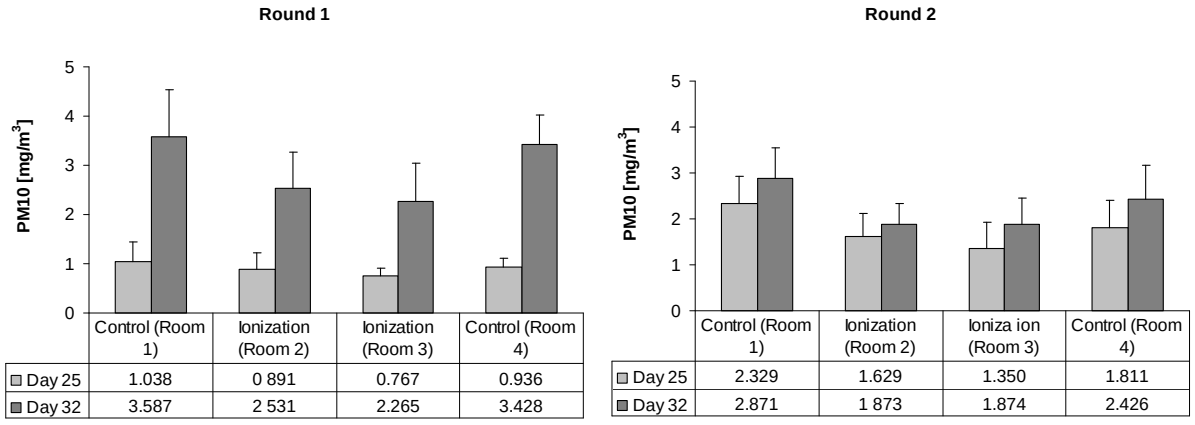

Figure 15 Mean PM10 concentrations (mg/m^3) and standard deviations at human's breathing height, during personal sampling on days 25 and 32, with DustTraks, for round 1 (left) and round 2 (right)

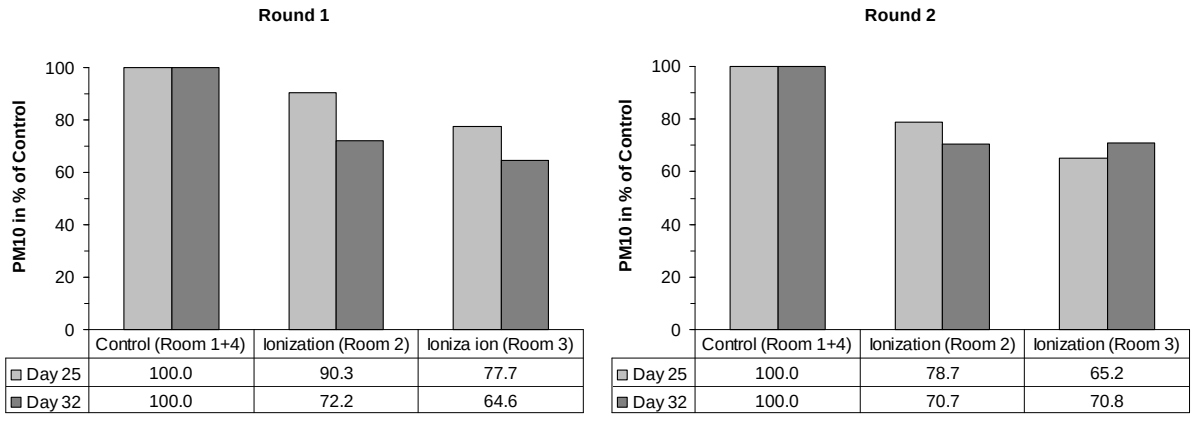

Figure 16 PM10 concentrations expressed as percentage (%) of concentration in control rooms vs. ionization rooms, on days 25 and 32, for round 1 (left) and round 2 (right)

3.5 Particle size and particle counts

Particle counts per size range were generally higher in control compared with ionization rooms. This trend varied in time. A decrease in the relative difference in particle counts in control and ionization rooms in all measured size ranges occurred from day 5 (round 2). Reduction in particle counts on day 5 was about 78% for all size ranges, and varied along time from 28% (day 19), 43% (day 26), being the lowest at 24% (day 34). Over the entire measured range (0.25 to 32 µm), two high reduction peaks were observed, one for particles between 0.58 and 1 µm, and one for particles between 5 and 30 µm, showing mean reduction percentages of approximately 40% (Figure 17). The middle particle size ranges (from 1.30 to 2 µm), and the smallest ranges (0.28 to 0.35 µm) showed the lowest mean reductions. Dust reduction percentages were in concordance with our findings reported for 24 hour PM10 measurements using cyclones, as well as the decrease in reduction towards the end of the rearing cycle. Data for measured particle counts for round 1 and round 2 are shown in Appendix 4.

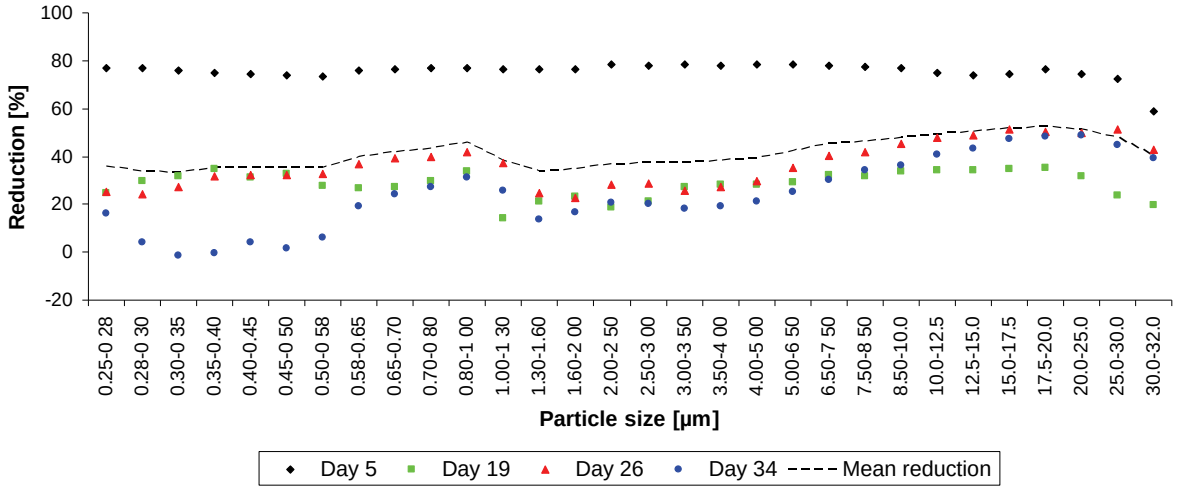

Figure 17 Mean reduction (%) per size range from 0.25 to 32 µm, in particle counts, between the control and ionization rooms, and daily reduction observed, on days 5, 19, 26 and 34 in round 2. Dashed line shows mean reduction percentage, calculated from the mean reduction at each day

3.6 Micro-organisms emissions

No clear trend in airborne micro-organisms emissions was observed over the experiment. Mean (SD) total bacteria emissions were 25.4 (9.5) log cfu/h per bird, control; 24.6 (6.5) log cfu/h per bird, ionization, for round 1. Mean (SD) total bacteria emissions were similar for round 2, 20.2 (7.1) log cfu/h per bird, control; 20.8 (8.4) log cfu/h per bird, ionization. Mean total bacteria emissions generally increased along time (Figure 18), as ventilation rates increased.

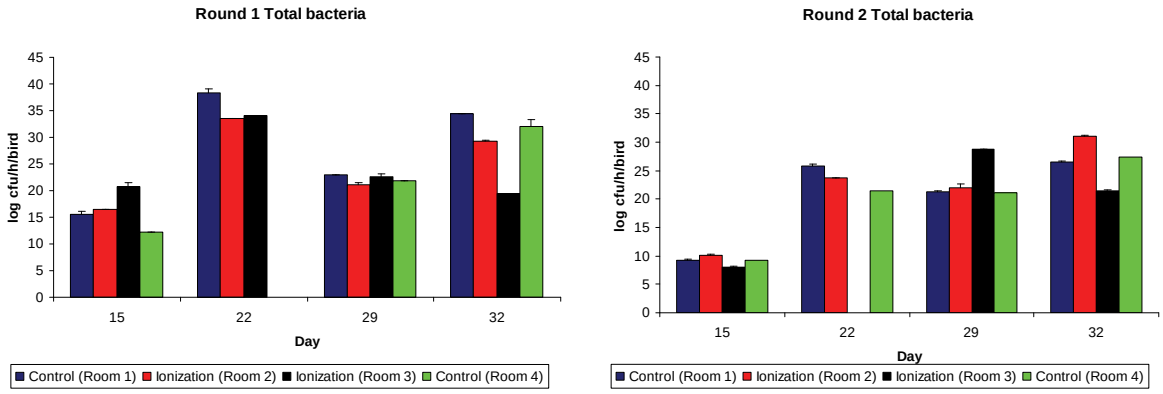

Figure 18 Mean total bacteria emissions (log cfu/h per bird) on days 15, 22, 29 and 32, for round 1 (left) and round 2 (right)

Mean (SD) airborne fungi emissions were 10.9 (4.2) log cfu/h per bird, control; 11.5 (4.8) log cfu/h per bird, ionization, for round 1. Mean (SD) airborne fungi emissions were higher for round 2, 18.0 (6.4) log cfu/h per bird, control; 18.2 (7.2) log cfu/h per bird, ionization. Mean airborne fungi emissions also showed an increasing trend along time (Figure 19).

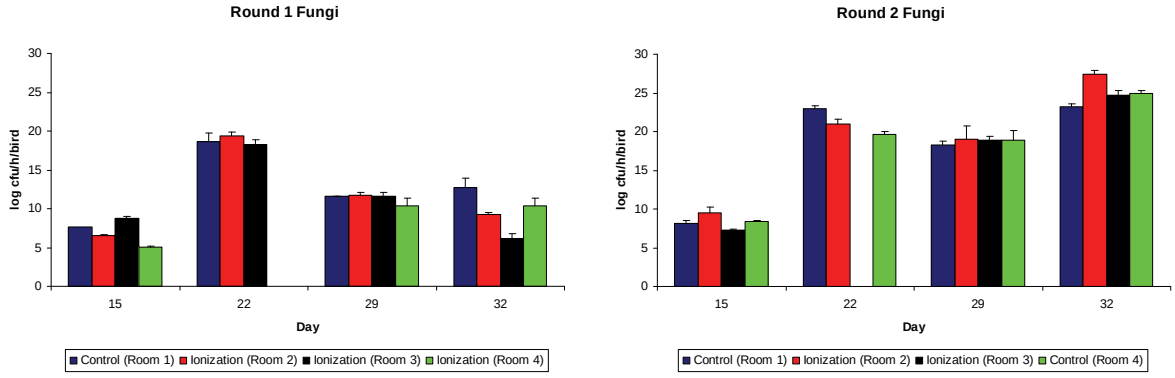

Figure 19 Mean fungi emissions (log cfu/h per bird) on days 15, 22, 29 and 32, for round 1 (left) and round 2 (right)

3.7 Odour emissions

Odour emissions were similar in control and treatment rooms. Mean (SD) odour emissions were 1.0 (0.53) ou_E/s per bird, control; 1.0 (0.59) ou_E/s per bird, ionization for round 1. Mean (SD) odour emissions were 1.0 (0.90) ou_E/s per bird, control; 1.2 (0.50) ou_E/s per bird, ionization for round 2. Measurements done on day 24 and 31 for both rounds showed unclear patter of odour emissions along time (Figure 20).

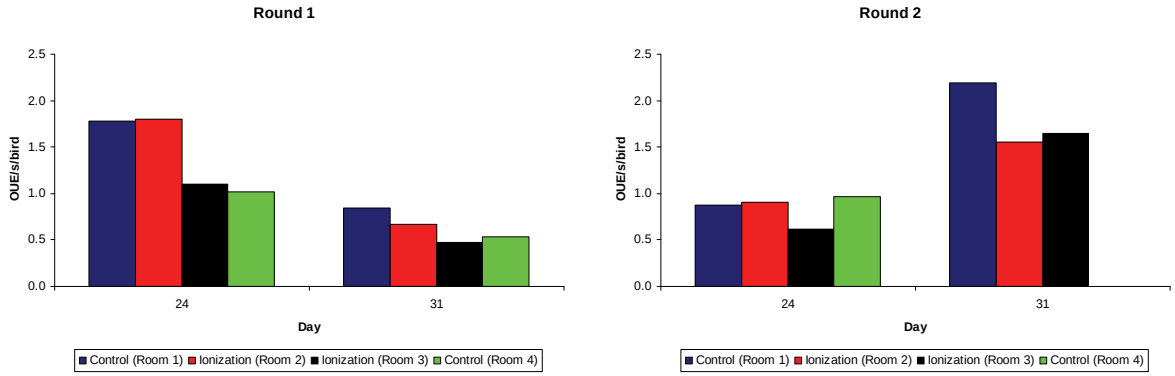

Figure 20 Mean odour emissions (ou_E/s per bird) on days 24 and 31, for round 1 (left) and round 2 (right)

3.8 Ammonia emissions

Total ammonia emissions per bird per year were similar in control rooms (49 g/year per bird), and ionization rooms (47 g/year per bird) rooms, for round 1. For round 2, total ammonia emission were also similar in the control rooms (30 g/year per bird), and ionization rooms (35 g/year per bird). Cumulative ammonia emissions along time were higher in round 1 (15 kg) compared with round 2 (10 kg) (Figure 21). Dynamics of emissions were similar for the first 20 days of the rearing cycle in both rounds, but slightly decreased in round 2 after day 20. Ammonia emission pattern is shown in Appendix 5.

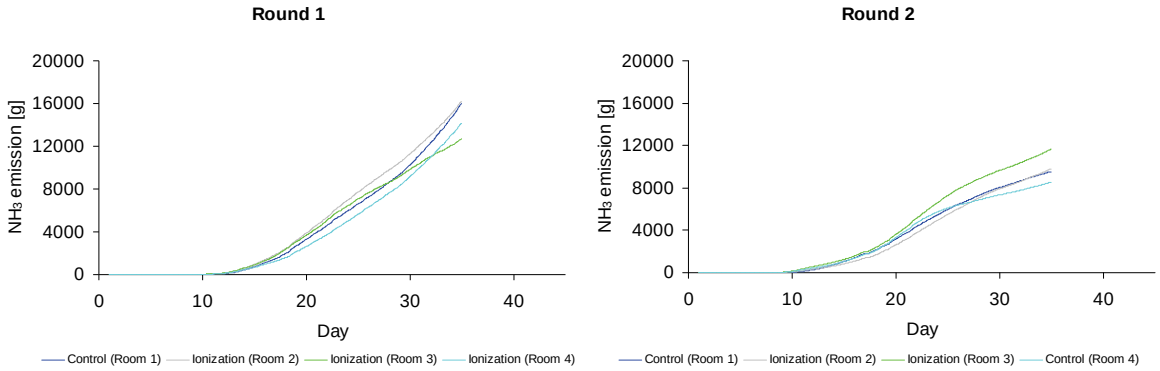

Figure 21 Cumulative ammonia emissions (g) over the rearing cycle, for round 1 (left) and round 2 (right)

3.9 Animal production

There were no statistically significant differences in broiler performance data observed in ionization and control rooms in this experiment. Table 5 provides a summary of the birds' performance data where it can be seen how consumption variables, growth and lesions were very similar in ionization and control rooms.

Table 5 Summary of birds' performance and foot-pad lesions for each treatment and for both flocks. Mean values and standard deviations (SD)

	Weight gain (g day^{-1} bird^{-1})	SD	Mortality (%)	SD	Feed conversion (kg feed/kg bird)	SD	Water consumption (mL day^{-1} bird^{-1})	SD	Foot-pad lesions (scores)	
									Broiler house	Slaughter house
First rearing cycle										
Control	57.5	0.2	3.3	0.3	1.632	0.025	159.9	2.5	63	32
Ionization	57.5	0.1	3.0	0.5	1.650	0.005	160.6	0.7	66	39
Second rearing cycle										
Control	56.5	1.5	2.2	0.4	1.635	0.014	163.0	1.3	113	174
Ionization	56.8	0.5	2.9	0.2	1.629	0.014	163.0	1.5	106	173
Overall mean										
Control	57.0	1.0	2.8	0.7	1.633	0.017	161.4	2.4	88	103
Ionization	57.1	0.5	2.9	0.3	1.639	0.015	161.8	1.7	86	106

3.10 Scoring of the exterior of the broilers

Table 6 shows the external quality of the broilers at the end of the growing period (day 33). No effects were found of ionization on external quality of the broilers for all measured parameters.

Table 6 External quality of the broilers on 33 days of age

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Breast dirtiness						
None	2%	2%	1%	0%	1%	1%
Mild	69%	66%	52%	61%	60%	63%
Intermediate	28%	31%	48%	38%	38%	34%
Severe	2%	2%	0%	2%	1%	2%
Breast irritations						
None	60%	56%	53%	52%	57%	54%
Mild	39%	40%	35%	45%	37%	42%
Intermediate	2%	5%	6%	3%	4%	4%
Severe	0%	0%	0%	1%	0%	0%
Scabby hips (thigh scratches)						
None	52%	57%	75%	65%	63%	61%
Mild	39%	35%	22%	30%	31%	32%
Intermediate	8%	9%	4%	4%	6%	6%
Severe	2%	1%	0%	2%	1%	1%
Hock burns						
None	24%	35%	41%	33%	33%	34%
Mild	56%	47%	52%	61%	54%	54%
Intermediate	21%	19%	8%	7%	14%	13%
Severe	0%	0%	0%	0%	0%	0%
Foot pad lesions *						
None	19%	16%	5%	2%	12%	9%
Mild	67%	69%	52%	60%	59%	64%
Severe	15%	16%	44%	38%	29%	27%
FPS **						
Poultry house	63	66	113	106	88	86
Slaughter house	32	39	174	173	103	106

* Examined according criteria (Swedish/Danish method) of the upcoming EU animal welfare regulation broilers (3 classes: 0, 1, 2)
** FPS (Foot Pad Score) = {[(n class 0 * 0) + (n class 1 * 0,5) + (n class 2 * 2)] / n total}*100)

3.11 Bedding

From table 7 it can be seen that visual litter quality was not influenced by the ionization system. The visually determined looseliness and moisture of the bedding were very similar between the ionization and the control rooms. Table 8 shows the measured dry matter content of the litter for the ionization and control treatments. The dry matter content was very similar between the treatments as well.

Table 7 Visual litter quality on 14, 28 and 35 days of age

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Day 14						
Looseliness *	7,7	7,8	7,7	7,3	7,7	7,6
Moisture **	6,5	6,7	6,7	6,4	6,6	6,5
Day 28						
Looseliness *	5,2	4,8	2,5	2,9	3,8	3,9
Moisture **	-	-	-	-	-	-
Day 35						
Looseliness *	-	-	-	-	-	-
Moisture **	6,0	5,5	3,2	3,2	4,6	4,3
Overall						
Looseliness *	6,2	5,7	3,0	3,3	4,6	4,5
Moisture **	6,0	6,0	3,5	4,0	4,8	5,0

* Looseliness: score 1 (complete plate, no loose litter) – score 10 (complete loose litter), see Appendix 8
** Moisture: score 1 (litter looking very wet) – score 10 (litter looking very dry), see Appendix 8

Table 8 Dry matter content (%) of the litter on 14, 28 and 35 days of age

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Day 14	65,6	63,0	68,3	69,5	66,9	66,2
Day 28	69,7	71,1	49,1	52,0	62,8	61,6
Day 35	63,1	63,2	54,8	58,5	59,0	60,9

4 Discussion

Some of the drawbacks reported for ionization systems such as ozone formation and ultra fine particle generations were tested in the experiment. It was shown that the ionization system did not produce excessive amounts of ozone, nor was an increase of ultra fine particle formation observed. Ozone concentrations could not be detected with gas tubes with a detection limit of 0.01 ppm, The typical ozone smell could, however, be detected with the human nose at the start of the growing period, at low ventilation rates. Other studies have reported ozone concentrations in the range from 0.01 to 0.165 ppm (Britigan *et al.*, 2006). Ultra fine particle concentrations were lower in ionization rooms compared with the control rooms. Results suggest a low rate of ultra fine particle formation in ionization rooms, at least below the rate of ultra fine particle formation in control rooms. Results showed that ion levels were more or less stable along time.

The effect of ionization on dust, in this experiment, was in agreement with the lower part of reduction ranges reported in other studies. Higher reductions of dust, 43% in a broiler house (Ritz *et al.*, 2006), and 61% in a broiler breeder house (Mitchell *et al.*, 2004) have been observed. These higher reduction percentages are probably expressed as total dust, whereas in our study differential dust fractions were measured. Dust measurements in these studies were furthermore done using light scattering devices which could be affected by particle charges, as they have a plastic sampling inlet, usually positively charged, which could cause attraction of negatively charged particles, and thus loss of particle mass measurement in the treated houses (Lyngtveit and Eduard, 1997). When using gravimetric analysis to measure dust mass, this effect is less probable, because the electrical charge is smaller (Lyngtveit and Eduard, 1997).

Reduction efficiencies in our experiment, expressed as the relative difference in PM emissions in the control and ionization rooms were, calculated at logarithmic scale, similar for PM10 (34%) compared with PM2.5 (33%). There was a tendency that PM2.5 reductions decreased with age of the birds. Because dust emissions are increasing exponentially with the age of the birds, the calculated mean PM2.5 reduction at normal scale (10%) was lower than the calculated mean reduction at logarithmic scale (33%). The negative reduction in PM2.5 emission on day 33 in round 1 may have been caused by accumulated dust on objects and surfaces becoming airborne again through activity of the animals and through the smaller reduction efficiency of ionization for smaller particles. For determining the total effect of a dust reducing system calculations at normal scale seem to be most relevant. Personal dust load of PM10 was reduced at a similar level as PM10 emissions, by approximately 30%.

Reductions were higher for particles in the upper size ranges, above 5 µm. Higher reduction efficiencies in relation to increased particle size have been reported in other studies. Reductions of total dust, in a pig house, were 30% higher than the reductions of PM2.5 and PM10, although no differences in reduction were found between PM2.5 and PM10 (Nicolai and Hofer, 2008). Higher reductions for particles bigger than 3 µm (Rosentrater, 2003), and bigger than 5 µm (Tanaka and Zhang, 1996), compared with smaller particles, have also been reported. Also Grabarczyk (2001) and Mayya *et al.* (2004) reported that reduction of particles by ionization is a size-dependent process. This is because of distinct particle charging mechanisms acting on small particles (<0.1 µm) which are charged by thermal charging mechanisms; compared with bigger particles (> 0.5 µm) which are charged by field charging mechanisms. In thermal charging, the charge acquired by particles is proportional to the diameter, whereas in field charging, it is proportional to the square of the diameter (Bundy, 1984). Another possible explanation is the higher probability of ions being attached to bigger particles than to smaller particles, because the extent to which ions can attach to particles depends on particle size and shape (Kunkel, 1950), being the mean particle size generally bigger in PM10, compared to PM2.5. A higher reduction in concentrations of big particles (> 2 µm), may also reduce the probability of aggregation of small particles to big particles, and so cause a decrease in reduction of the small particles (Tanaka and Zhang, 1996).

A clear difference was found in dust emissions between the first and the second round. The higher humidity levels and the lower dry matter content of the bedding seem to be the main cause of the lower emissions in the second round. Also ammonia emissions were a lot lower in the second compared to the first round. This is not in agreement with the general accepted view that ammonia emission decreases at higher dry matter content of the bedding material. It might be that the wet upper layer of the bedding material formed a crust which prevented ammonia being emitted from the bottom layers of the bedding.

Dust concentrations measured in the experiment followed a normal increase in time, with age of the birds, which is in agreement with other studies. Emissions also increased in time, as ventilation rates and dust concentrations increased. Dust reductions by the ionization systems showed a negative relation with increased dust

concentrations and increased ventilation rates, over the rearing cycle, thus reductions decreased to the end of the rearing cycle. In growing pigs, a decrease in dust reduction using ionization was observed after week 3, and even showed negative efficiency at the end of the growing period (weeks 6 and 7) (Tanaka and Zhang, 1996). Such differences are probably explained by three processes: higher ventilation rates along time, hence, higher airflow rates inside the ionization rooms and therefore a decrease in residence time of charged particles and less chance of particles to settle down on surfaces; a decrease in free ion concentrations in the air in the ionization rooms with increasing PM concentrations and ventilation rates; increasing dust layer of deposited dust on room surfaces along time and decreasing attraction of dust to these surfaces. The two steps in particle removal explained by Mayya *et al.* (2004), being particle charging, and electro-migration of charged particles due to electric fields, may be considerably affected by these three processes: ventilation rate, ion concentrations, and increasing dust layer. Particle charging, and the charges acquired by particles, can decrease at higher particle concentrations because of ion concentration reduction and decreased residence time of particles because of increased removal rates (Mayya *et al.*, 2004).

Negative relationships between ventilation rate and thickness of the dust layer and dust reductions have been stated in different studies (Tanaka and Zhang, 1996; Nicolai and Hofer, 2008; Bundy, 1984). The electrostatic voltage is related to the thickness of the deposited dust layer and the electrical resistance of dust, and it increases as more dust is accumulated on collection plates or grounded surfaces (St George and Feddes, 1995a). High electrostatic voltage difference between the building surfaces and dust layer can insulate the surfaces, and reduce the attraction of airborne dust to building surfaces (Tanaka and Zhang, 1996). To counteract this effect, a higher voltage can be applied to the discharge electrodes, however, this will increase the risk of ozone formation (Boelter and Davidson, 1997; St George and Feddes, 1995b), and undesired charging of objects in the rooms, because of high electrostatic electricity level (Grabarczyk, 2001). Electric fields increase with particle concentration (Mayya *et al.*, 2004). Minimal effect of cleaning of the collection plates, however, could be observed in dust PM10 concentrations. The use of mechanical cleaning and a dust collection system in round 2 did not show a clear improvement of the reduction efficiency.

No relevant effect of ionization on odour or ammonia was observed. Some studies have presented high ammonia reductions using ionization in broiler houses (Mitchell *et al.*, 2004; Ritz *et al.*, 2006), although a clear explanation of the principle behind it is still missing. Some reduction in ammonia and odours could be expected, as a (small) proportion of these compounds found in the air of livestock houses are adsorbed on dust (Koziel *et al.*, 2007; Takai *et al.*, 2002). It should be noted that in our measurements dust was removed from the air before ammonia and odour concentrations were analysed. Micro-organism emissions were also not affected by the ionization system, despite the reported potential of ions to kill micro-organisms, and the reductions in microbial load observed in some studies (Chiumenti and Guercini, 1990; Grinshpun *et al.*, 2004; Holt *et al.*, 1999). A possible explanation could be a difference in sampling system; in our study impingement method was used for sampling, while in the mentioned references the impaction method on culture plates was used. Impingement into liquid media tends to give higher colony counts for environments where micro-organisms are carried as aggregates, compared to impaction on culture plates. The ionization system may cause more aggregation of micro-organisms.

5 Conclusions

Ionization has a potential to reduce dust, and can be a practical system to be applied at farm level in broiler houses. From our results, we can conclude the following:

- The tested ionization system (EPI system) is an efficient and appropriate dust reduction technique for broiler houses, with minimal maintenance and labour needs in case cleaning of the collection plates is mechanised.
- Ionization can reduce PM10 and PM2.5 concentrations and emissions in broiler houses by approximately 36% and 10%, respectively.
- Ionization seems to be more effective for particles in the coarse fractions (> 5 µm).
- Ionization does not have a relevant effect on micro-organism, odour or ammonia emissions.
- Ionization does not show any effect on broiler performance nor on litter quality.

6 Recommendations

It is recommended that the results of this study are validated and demonstrated on practical farms to facilitate implementation of ionization systems on broiler farms. While the system also has potential for layer housing, it is recommended that the ionization systems is tested in this environment, as well.

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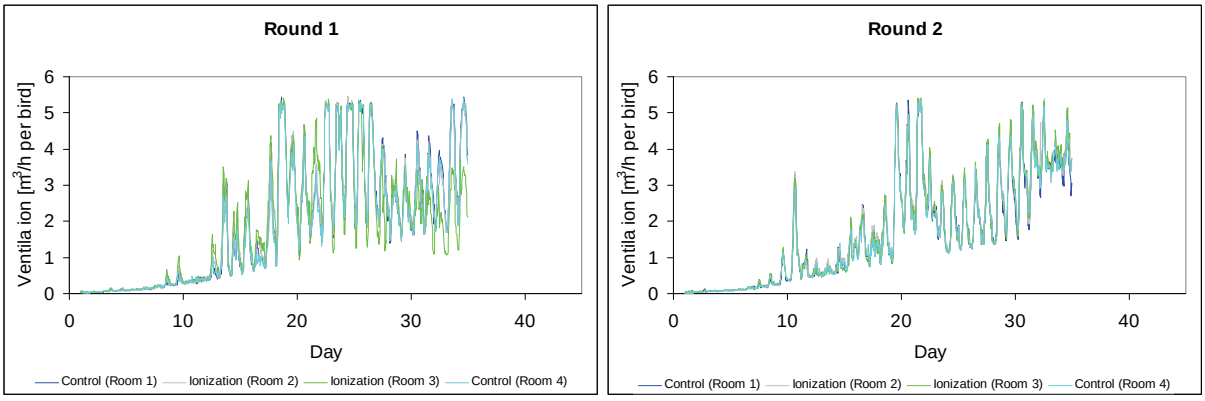
Appendices

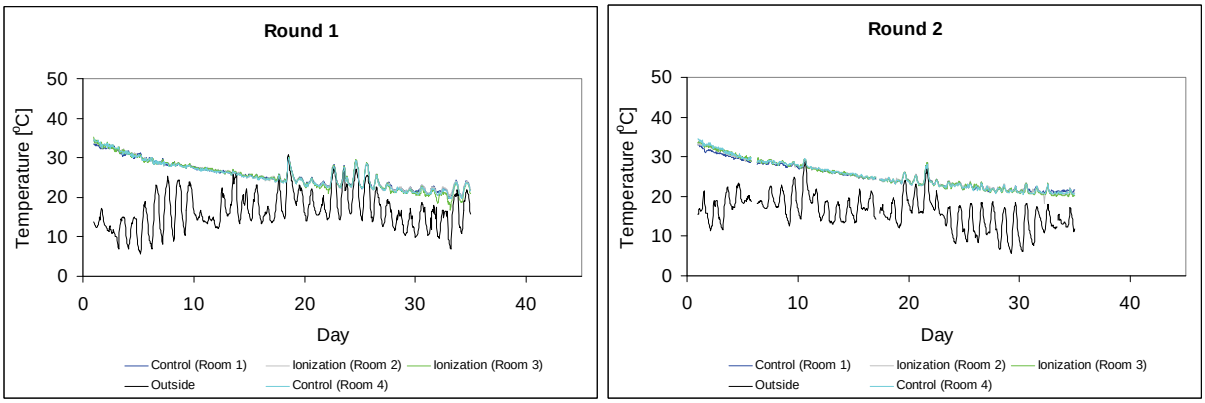
Appendix 1 Ventilation rate and environmental data for round 1 and round 2

	Outside	Control Room 1	Ionization Room 2	Ionization Room 3	Control Room 4
Total ventilation (m^3/h)					
Round 1		5092	5180	4869	4945
Round 2		4408	4596	4557	4410
Total ventilation (m^3/h per bird)					
Round 1		1.90	1.93	1.82	1.85
Round 2		1.65	1.72	1.70	1.65
Temperature (°C)					
Round 1	16.6	25.8	25.8	25.6	25.6
Round 2	16.1	25.1	25.3	25.2	25.3
Relative humidity (%)					
Round 1		62.0	56.0	59.2	56.7
Round 2		63.6	64.5	67.9	64.7

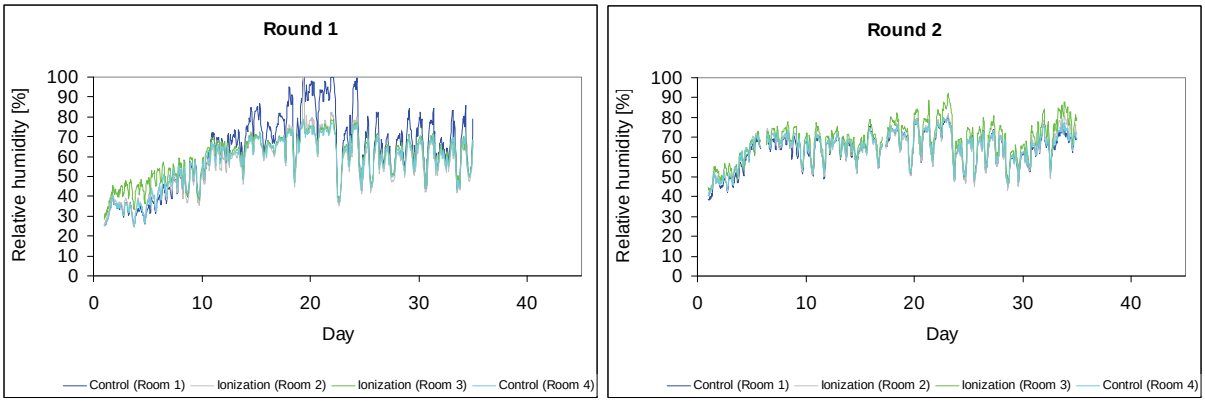
Ventilation rate (m^3/h per bird) for round 1 and round 2, over the rearing cycle



Temperature (ºC) for round 1 and round 2, over the rearing cycle

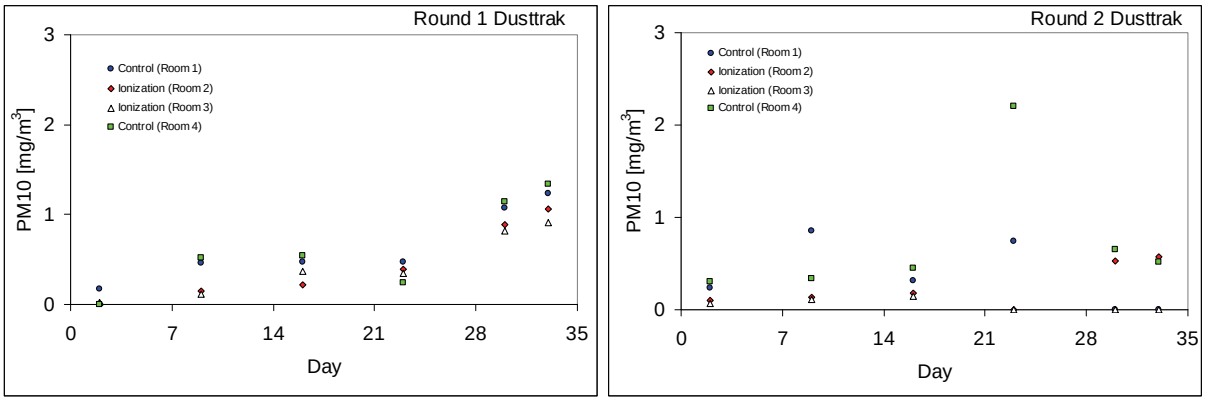


Relative humidity (%) for round 1 and round 2, over the rearing cycle

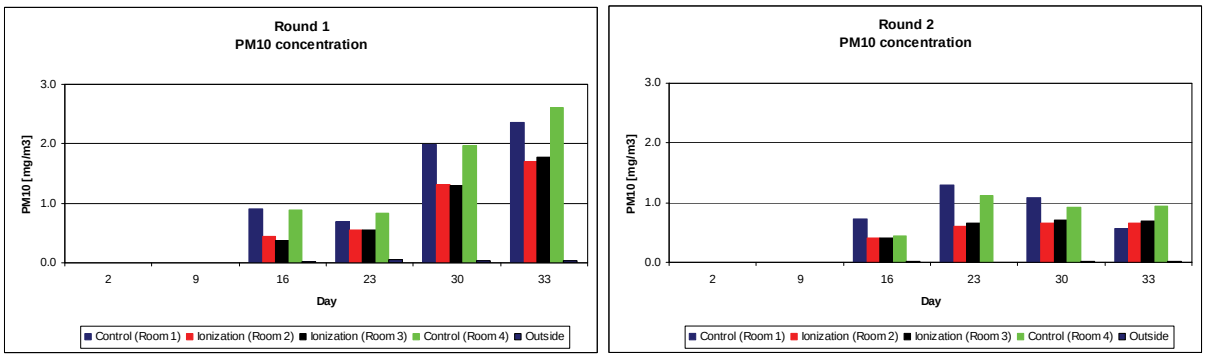


Appendix 2 PM10 and PM2.5 concentrations and emissions for round 1 and round 2

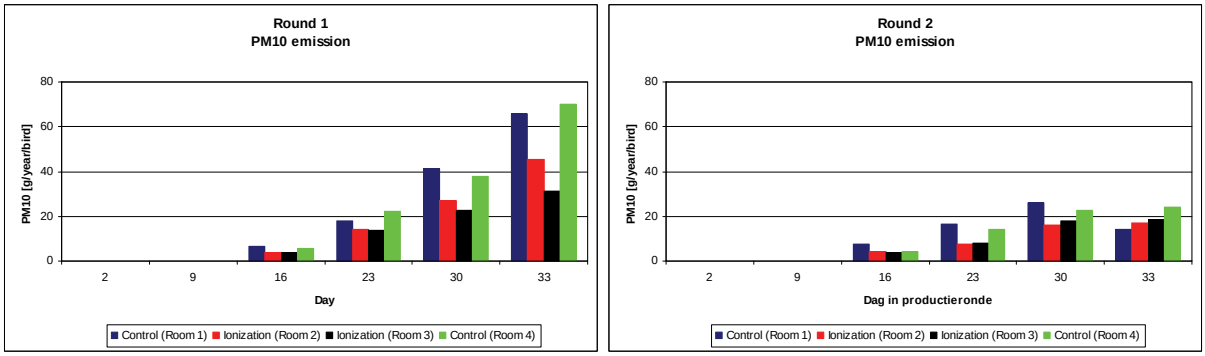
A. DustTrak PM10 (mg/m^3) mean values for round 1 and round 2



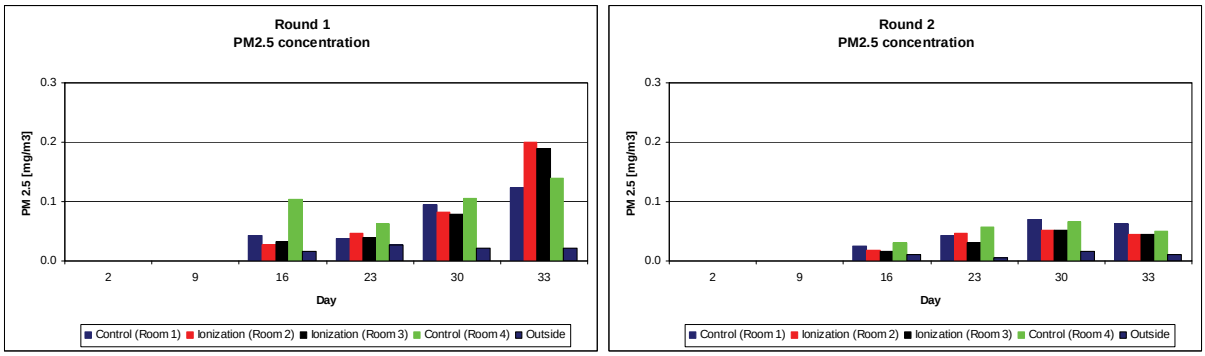
B. Cyclone PM10 (mg/m^3) concentrations for round 1 and round 2



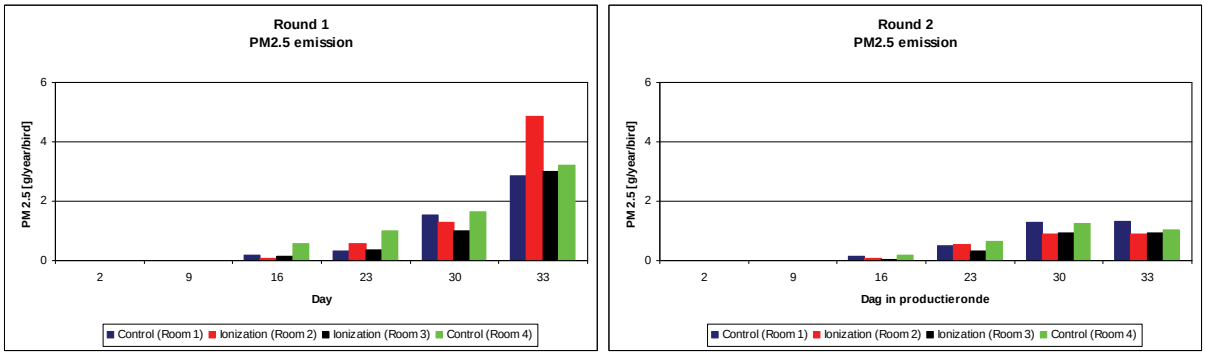
C. PM10 emissions (g/year per bird) for round 1 and round 2



D. Cyclone PM2.5 (mg/m^3) concentrations for round 1and round 2

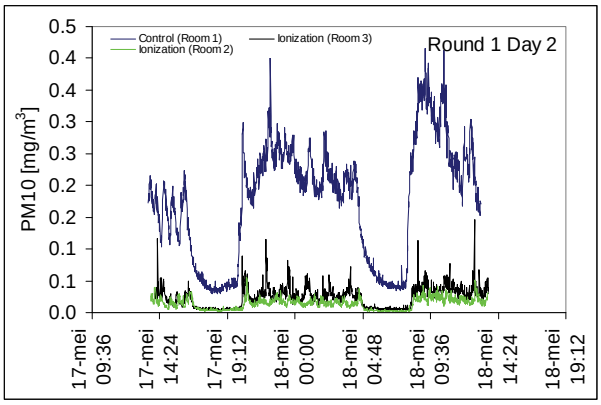


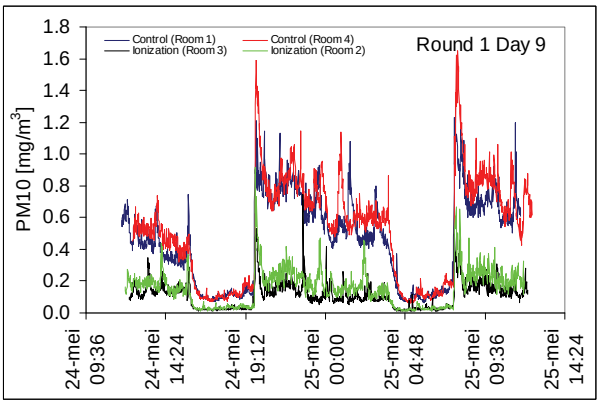
E. PM2.5 emissions (g/year per bird) for round 1 and round 2

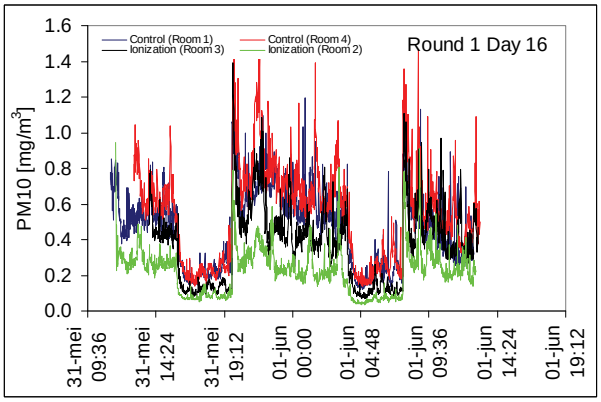


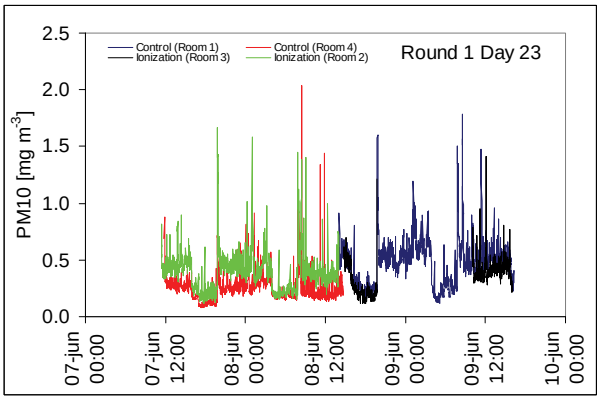
Appendix 3 Continuous 24 h DustTrak PM10 data for round 1 and round 2

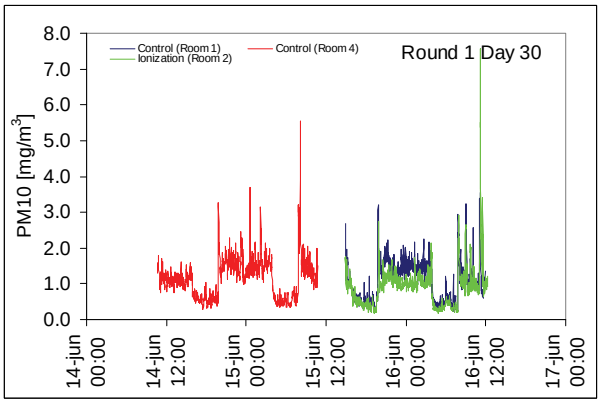
A. Continuous 24 h DustTrak PM10 (mg/m^3) values on days 2, 9, 16, 23, 30 and 33 in round 1

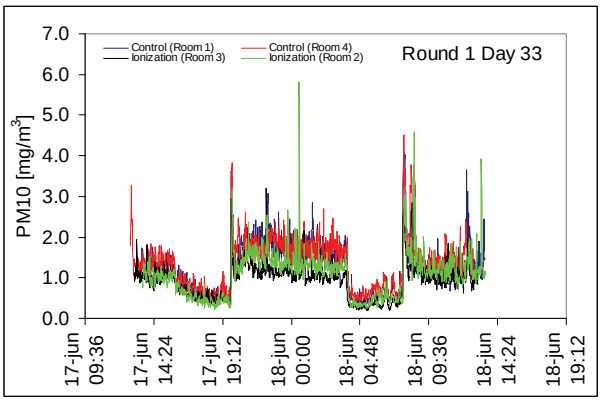




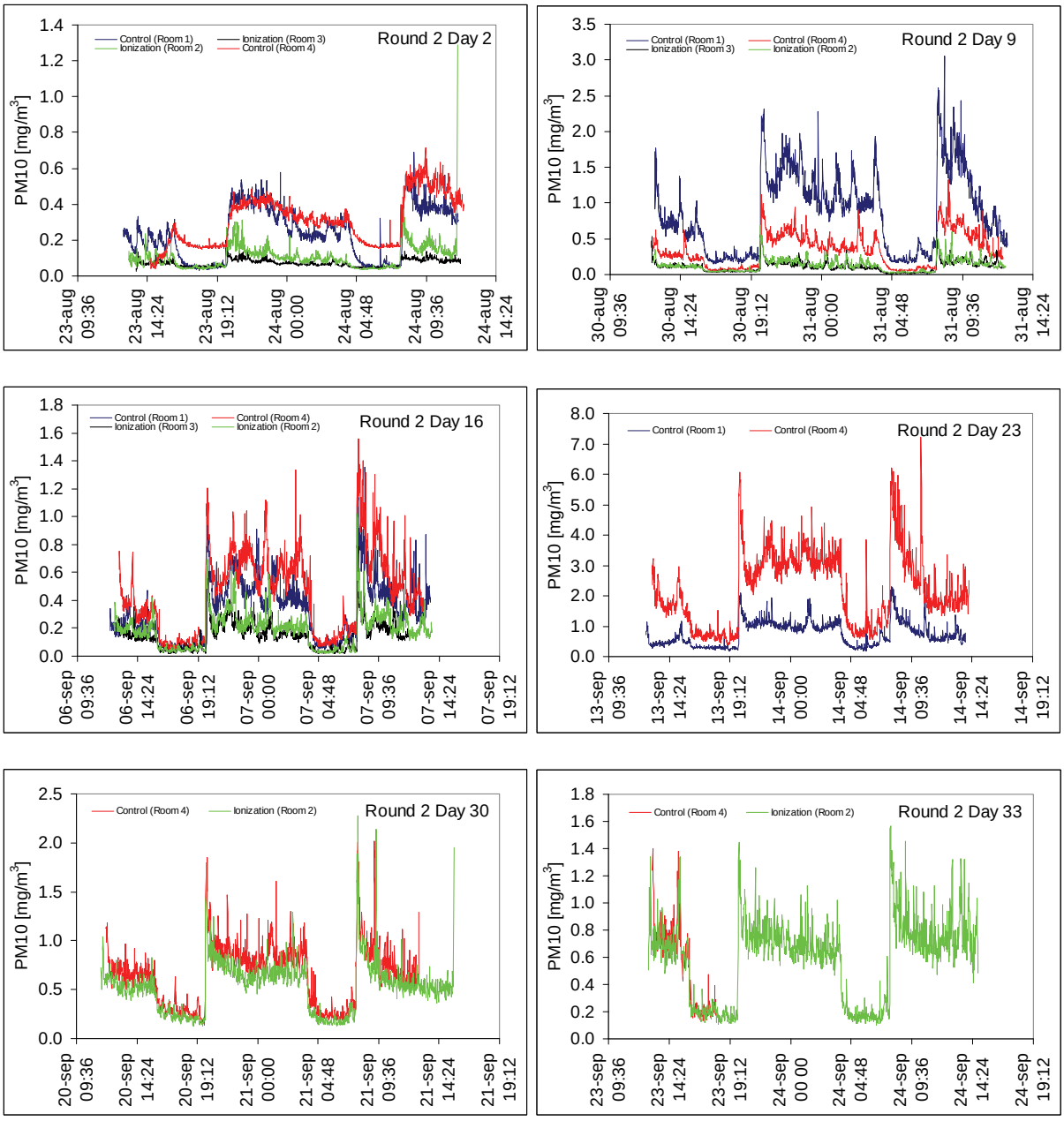






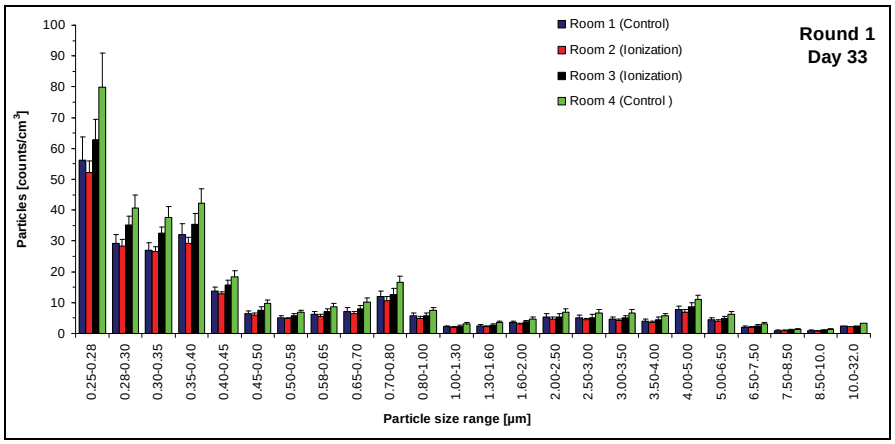


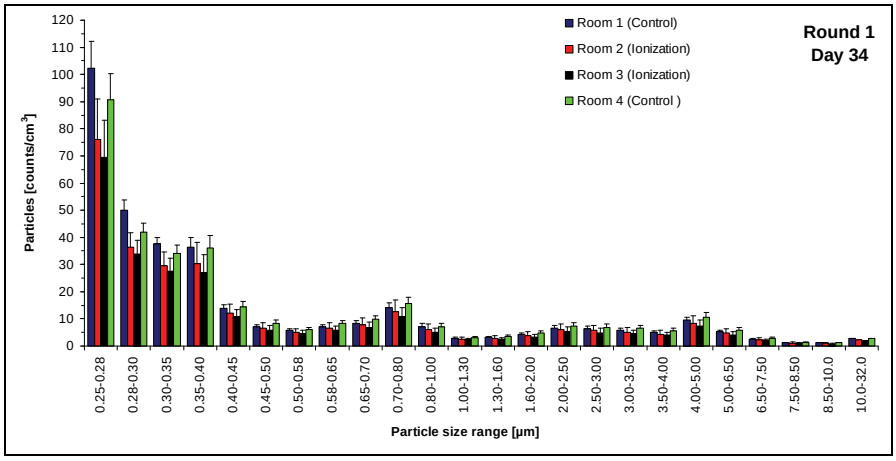
B. Continuous 24 h DustTrak PM10 (mg/m^3) values on days 2, 9, 16, 23, 30 and 33 in round 2



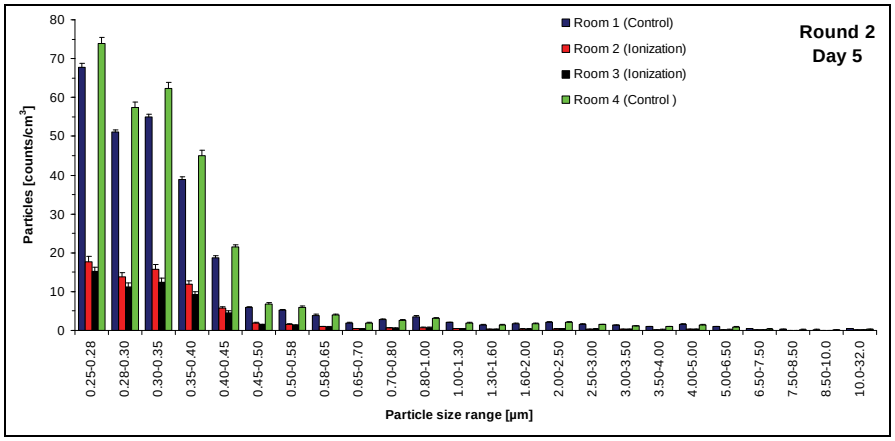
Appendix 4 Particle counts and size distributions for round 1 and 2

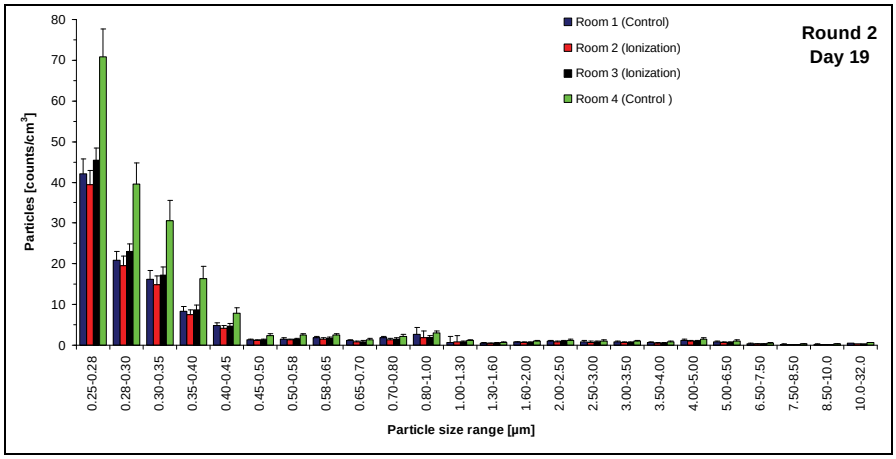
A. Particle counts per size range, for day 33 and 34 in round 1

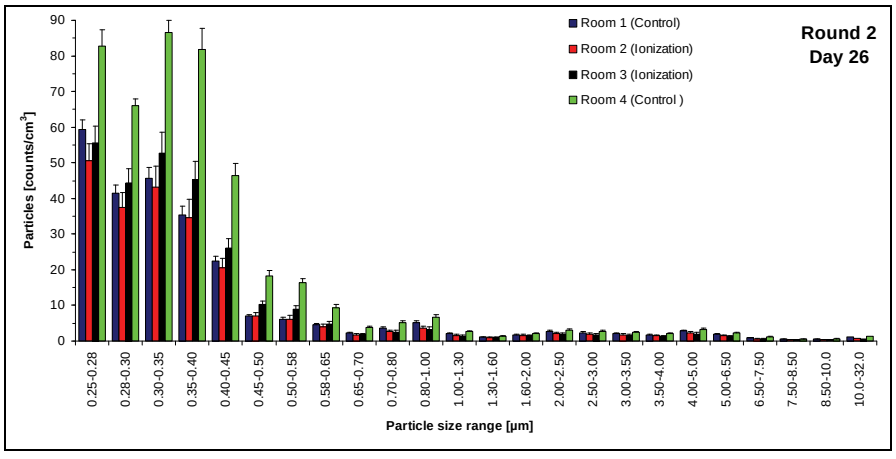


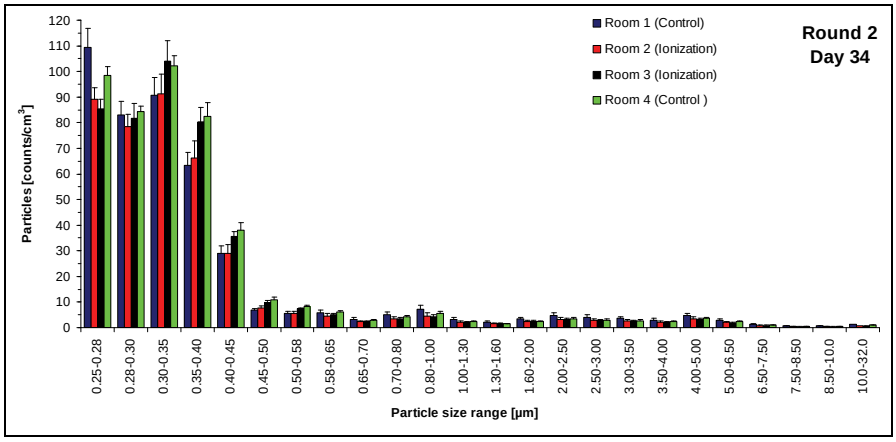


B. Particle counts per size range, for day 5, 19, 26 and 34 in round 2



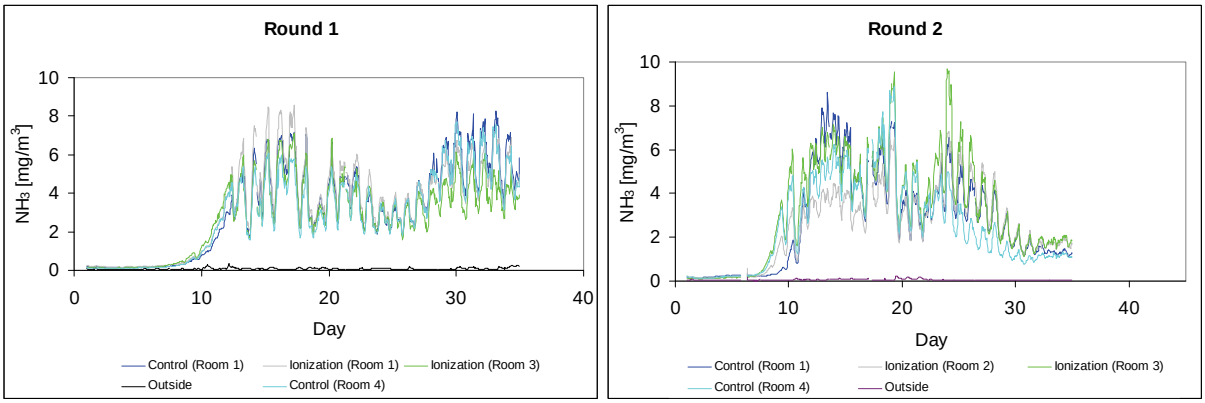




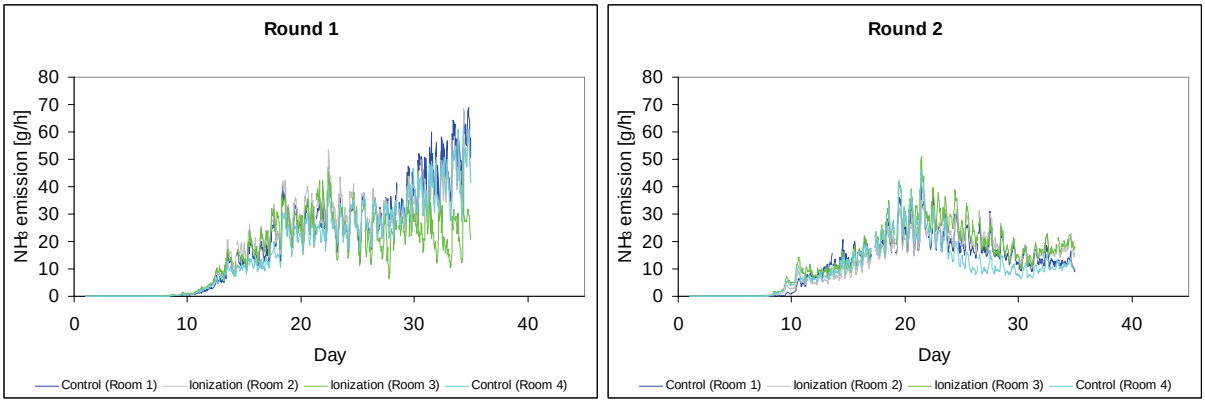


Appendix 5 Ammonia concentrations and emissions

A. Continuous ammonia concentrations (mg/m^3) for round 1 and round 2



B. Continuous ammonia emissions (g/h) for round 1 and round 2



Appendix 6 Broiler performance data of broilers in the control and ionization rooms during the two rounds

A. Performance of broilers from 0 – 21 days

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Weight day 0 (g/bird)	45	45	42	42	44	44
Weight day 21 (g/bird)	933	931	945	946	939	938
Growth (g/bird)	888	886	903	904	895	895
Growth (g/(day.bird))	42.3	42.2	43.0	43.1	42.6	42.6
Mortality (%)	2.3	2.0	1.9	2.4	2.1	2.2
FCR (kg/kg) *	1.382	1.398	1.370	1.372	1.376	1.385
Total feed consumption (g/bird)	1227	1239	1236	1239	1231	1239
Feed consumption (g/(day.bird))	58.4	59.0	58.8	59.0	58.6	59.0
Water (ml/(day.bird))	103.1	103.3	103.0	103.2	103.0	103.3
Water/feed (kg/kg)	1.77	1.75	1.75	1.75	1.76	1.75

* FCR= Feed Conversion Rate

B. Performance of broilers from 22 – 35 days

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Weight day 35 (g/bird)	2056	2056	2018	2029	2037	2043
Growth (g/bird)	1123	1125	1074	1083	1098	1104
Growth (g/(day.bird))	80.2	80.4	76.7	77.4	78.5	78.9
Mortality (%)	1.0	1.0	0.3	0.5	0.7	0.7
FCR (kg/kg) *	1.830	1.848	1.859	1.845	1.844	1.846
Total feed consumption (g/bird)	2054	2079	1995	1999	2025	2039
Feed consumption (g/(day.bird))	146.7	148.5	142.6	142.8	144.6	145.7
Water (ml/(day.bird))	246.5	247.5	254.0	254.0	250.2	250.8
Water/feed (kg/kg)	1.68	1.67	1.78	1.78	1.73	1.72

* FCR= Feed Conversion Rate

C. Performance of broilers from 0 – 35 days

	Round 1		Round 2		Average	
	Control	Ionization	Control	Ionization	Control	Ionization
Weight day 0 (g/bird)	45	45	42	42	44	44
Weight day 35 (g/bird)	2056	2056	2018	2029	2037	2043
Growth (g/bird)	2011	2011	1976	1987	1993	1999
Growth (g/(day.bird))	57.5	57.5	56.5	56.8	57.0	57.1
Mortality (%)	3.3	3.0	2.2	2.9	2.8	2.9
FCR (kg/kg) *	1.632	1.650	1.635	1.629	1.633	1.639
Total feed consumption (g/bird)	3280	3318	3231	3238	3255	3278
Feed consumption (g/(day.bird))	93.7	94.8	92.3	92.5	93.0	93.7
Water (ml/(day.bird))	159.9	160.6	163.0	163.0	161.4	161.8
Water/feed (kg/kg)	1.71	1.70	1.77	1.76	1.74	1.73
EPF **	340	338	338	338	339	338

* FCR= Feed Conversion Rate

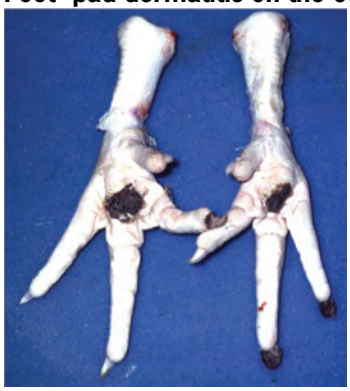
** EPF= European Production Factor

Appendix 7 Scoring method foot pad lesions

Foot-pad dermatitis in broilers – a photo guide to foot health classification

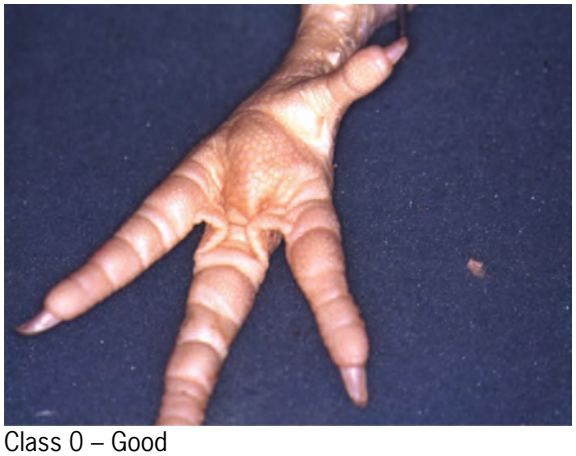
C. Berg
Department of Animal Environment and health
POB 234
SE- 532 23 Skara
Sweden

Foot- pad dermatitis on the central foot-pad

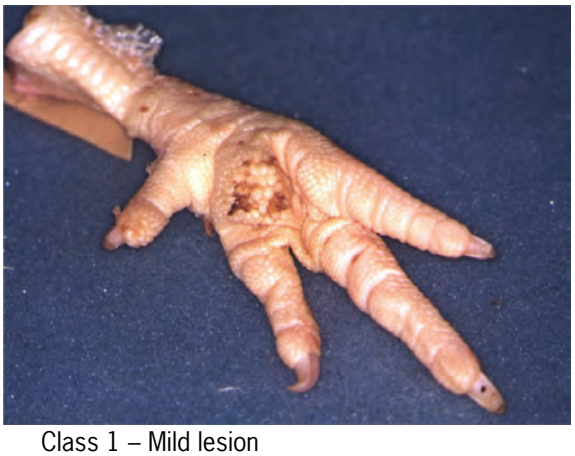


Classification of FPD

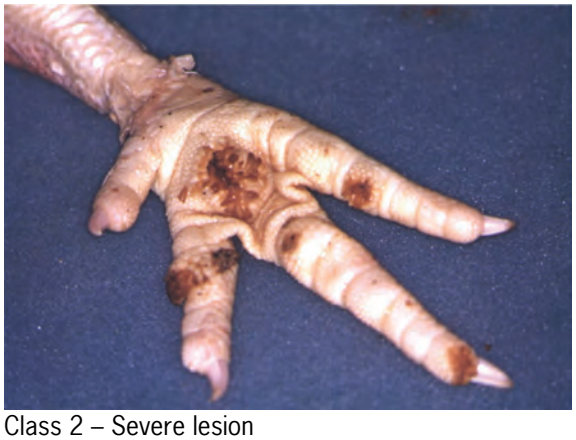
0: No lesion: no or very small and superficial lesions, slight discolouration on a limited area, mild hyoerkeratosis
1: Mild lesion: discolouration of the foot pad, superficial lesion, dark papillae
2: Severe lesion: ulcers or scabs, signs of haemmorrhages or swollen food pad



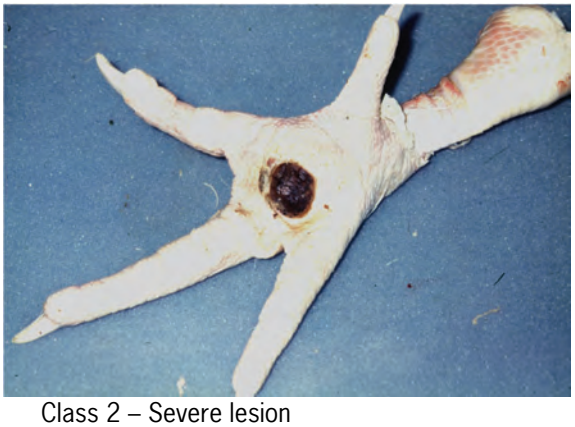
Class 0 – Good



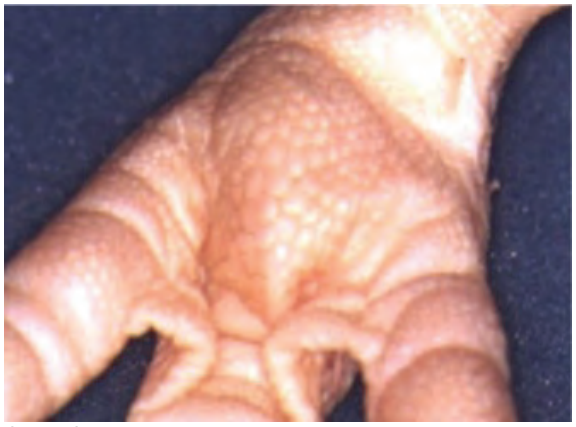
Class 1 – Mild lesion



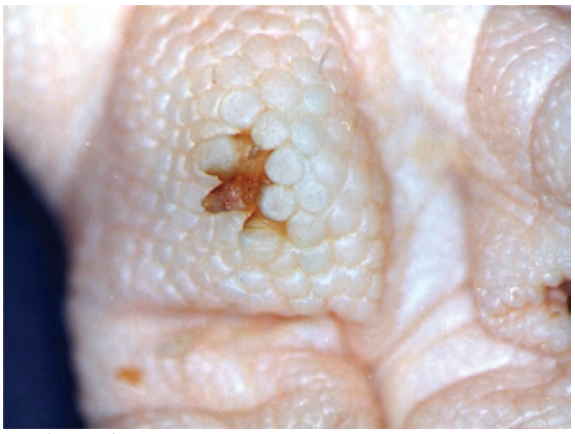
Class 2 – Severe lesion



Class 2 – Severe lesion



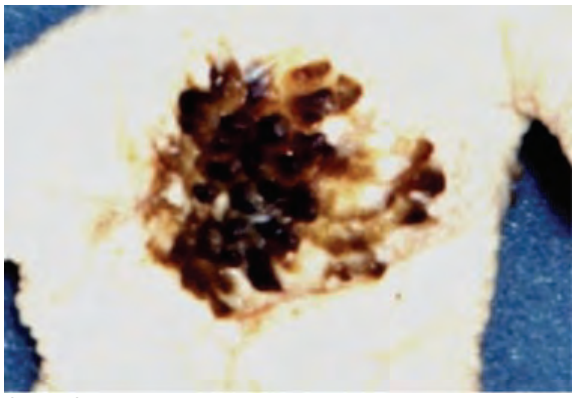
Class 0 – smooth, no lesions



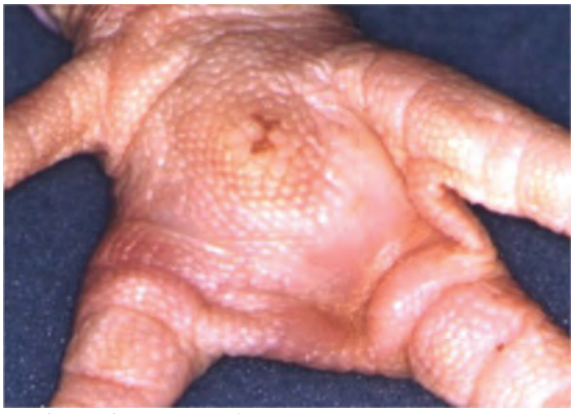
Class 0 – minor discolouration

Class 1 – discoloured papillae, no ulcer

Class 1 – larger discolouration, superficial



Class 2 – ulcer with scab



Class 2 – bumble foot, very swollen

Appendix 8 Protocol for visual scoring of bedding quality and sampling of bedding material

A. Visual scoring of bedding quality

A panel of 3-4 persons evaluates and scores both the visual looseliness and humidity of the bedding on a scale of 1 (very bad, 10 = very good). The tables below show the situations that correspond with the score that should be given. The scores should be noted on the 'Visual evaluation of bedding' form.

Visual looseliness	
Score	**Situation**
1	Bedding completely closed of, looks as a one massive plate
2	80-90% of the bedding surface is closed of
3	70-80% of the bedding surface is closed of
4	60-70% of the bedding surface is closed of
5	50-60% of the bedding surface is closed of
6	40% of the bedding surface is closed of
7	30% of the bedding surface is closed of
8	10% of the bedding surface is closed of
9	Bedding is completely loose, but formation of plates/closed of spots in the bedding has started
10	Bedding is completely loose, there are no plates/closed of spots in the bedding

Visual humidity	
Score	**Situation**
1	Bedding is wet; in all places boots sink into the bedding and water can be seen around the boots (seldomly seen)
2	Bedding is wet; only underneath the drinker lines boots sink into the bedding and water can be seen around the boots
3	Bedding is wet; only underneath the drinker lines boots sink into the bedding but no water can be seen around the boots
4	Bedding is wet and looks darkish; a ball can be made of the bedding, clear ridge formation underneath the drinker lines,
5	Bedding is wet and looks darkish; clear ridge formation underneath the drinker lines, all other bedding starts to close of as a massive plate
6	Mainly dry bedding, looks darkish in most places, small ridge formation underneath the drinker lines, bedding between drinker and feeder lines is still loose
7	Mainly dry bedding, looks darkish only underneath the drinker lines, rest of the bedding still has a light color, ridge formation is starting underneath the drinker lines
8	Mainly dry bedding, light color, no ridge formation underneath the drinker lines
9	Dry bedding, very light color
10	Very dry bedding (only seen after placement of the one day old chicks)

B. Bedding sampling procedure for determination of dry matter content

Take three bedding/manure samples per room.

When the feeder lines form a circuit, take the samples at three locations on a diagonal line, starting at the feed hopper, then at the drinker line between the feeder lines and finally at the feeder line.

When the feeder line is straight, take the samples at three locations: at the feeder line, at the drinker line and in the center between sub rooms (between the two pairs of [drinker line/feeder line/drinker line] at one side of the room).

Take the samples with a manure boring device or unloosen the bedding/manure material and take a handful. Put the samples per room together in a bucket, plastic bag or a stainless steel (rust-resisting steel) cup.