Pilots to reduce particulate matter emissions from poultry houses

Freshlight HD ionization lamps

Yvo Goselink, Hilko Ellen, Jos Huis in ’t Veld, Albert Winkel

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WAGENINGEN
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To mitigate the concentrations of fine particulate matter in livestock farming areas, techniques are needed which reduce emissions from poultry barns. In this pilot study, measurements were carried out on the ionization lights of the company Freshlight, installed inside a layer barn. In deviation from the measurement protocols, the so called “fine dust pilots” included one (instead of two) farm locations. The measurements show that the system reduces the emission of fine particulate matter (PM_{10}) with 41%.

PO Box 338, 6700 AH Wageningen, T 0317 48 39 53, E info.livestockresearch@wur.nl, www.wur.nl/livestock-research. Wageningen Livestock Research is part of Wageningen University & Research.

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Content

Foreword

In the quest for poultry farms for the possibilities of reducing the emission of particulate matter (PM10) from barns, a project consisting of eight pilots has been started in the Foodvalley Region. In the pilots, suppliers of new techniques or housing systems were given the opportunity to have measurements carried out into their effectiveness. The pilots were carried out under the responsibility and organization of the Practice Center for Emission Reduction Livestock Farming (PEV). Poultry farmers made their barn available as a test location for the pilots. Finally, Wageningen Livestock Research provided the scientific knowledge about livestock emissions and reduction techniques and carried out the measurements in the test barns. This report presents the results of the measurements using one of the techniques selected by the PEV. We would like to thank the employees of the PEV, the project team, the supplier, and the poultry farmer for the fine and constructive cooperation in the implementation of the measurements.

The authors

Summary

Reason and purpose

In some areas in the Netherlands, such as in the Food valley region, poultry houses are an important emission source of particulate matter (PM10) in the outside air that is associated with health effects in humans. In this pilot it was investigated to what extent the HD ionization lamps from Freshlight can reduce the emission of particulate matter from laying hen houses. Based on this measurement report, the technique can be included in national or regional regulations with a (provisional) reduction percentage for particulate matter. Entrepreneurs in livestock farming can then use this technique on their farm to reduce the burden on the environment with particulate matter.

Fine dust reduction system and test stable

Three rows with 16 HD ionization lamps each hung from the roof of the barn. The HD ionization lamps consisted of an LED TL and ionization part. The ionization part produces 300 * 10_6 ions per second with 12 carbon brushes. The ionisation part consumes 2.4 watts. In this laying hen house, there were 48 lamps with an ionisation part, the ion production was 16.8 * 10_6 ions per m² house surface. The ions that are produced change the electrical charge of dust particles. According to the supplier, the working principle consists of binding dust particles to water molecules in the air and the particles become heavier, these heavier particles deposit on the ground. The system does not use ventilation or recirculation. The system was installed in a renovated poultry house with 12,000 organic laying hens.

Measurement strategy and measurement methods

In this study, a so-called "case-control strategy over time" was used. This means that in principle the system was on for the entire production period, but that during each measurement, first 24 hours was measured with the system on (case), followed by a second period of 24 hours while the system was switched off (control). Emission-reducing techniques for animal housing are normally tested according to the measurement protocol as drawn up in the Netherlands and in the international VERA collective. These measurement protocols have been followed as much as possible. Contrary to the protocols, measurements were carried out at one instead of two company locations. An attempt was made to carry out the measurements in a balanced manner over the production period and the calendar year in order to obtain a representative estimate of the reduction, taking into account the influences of the production stage and season.

The measurements concerned: temperature and relative humidity, CO_2 concentration (for calculating the ventilation flow rate using the CO_2 balance method) and concentration of PM_{10}. The PM_{10} emission has been calculated from the combination of ventilation flow rate and PM_{10} concentration.

Results

A total of six measurements were performed, all of which could be used to determine the reduction percentage. The statistical analysis showed that the house temperature and the ventilation flow rate did not differ significantly between case and control days, which indicates a clear basis for comparison. PM_{10} emissions were significantly reduced by an average of 41%.

Conclusion

The HD ionization lamps from Freshlight can reduce the emission of PM_{10} in laying hen houses. Based on six measurements at one laying hen house, in which the relevant measurement protocols have been followed as much as possible, this reduction amounts to an average of 41%. This reduction is statistically significantly different from zero.

1 Introduction

1.1 Scientific problem description

Particulate matter, or PM_{10}, is a collective term for solid and liquid particles smaller than 10 micrometers[1] that are suspended in the air (EN 12341: 2014; CEN, 2014). After inhalation, these very small particles can penetrate deep into the respiratory tract. They can cause negative health effects, such as an increased risk of developing and worsening respiratory, lung, heart, and blood vessel diseases. Fine dust in the outside air is responsible for approximately 4% of the total disease burden. After smoking (13%), air pollution is therefore one of the most important risk factors (Health Council, 2018). Fine dust comes from natural sources (such as forest fires, wind erosion and sea salt particles) and from anthropogenic sources such as traffic and transport, industry, and the agricultural sector. The European air quality directive 2008/50 / EC contains limit values for, among other things, particulate matter in the outside air. The daily average concentration may not exceed 50 µg/m$_3$, whereby a maximum of 35 exceedance days are permitted annually. In addition, the concentration of particulate matter may not exceed 40 µg/m$_3$ on an annual average. The World Health Organization applies an Air Quality Guideline limit of an annual mean of a considerably lower 20 µg/m$_3$ (WHO, 2005). However, there is no threshold value for the effects of particulate matter, i.e. every microgram of particulate matter present in the air is bad for health.

The concentration and composition of particulate matter in the outside air varies from moment to moment (temporal variation) and from place to place (spatial variation). In urban areas, approximately two-thirds of the anthropogenic particulate matter present in the open air may come from emissions from traffic and transport, while in rural areas about half of the anthropogenic particulate matter present in the air may come from stable emissions and agriculture (Hendriks et al., 2013). Stables for poultry, pigs and cattle are - after traffic and industry - the third emission source of particulate matter in the Netherlands (Winkel et al., 2016). In barns, these particles mainly arise from manure, feathers, skin / hair, feed and straw (oisel) (Aarnink et al., 2011). Steel dust differs from urban or industrial dust in that it is of biological origin and is rich in microorganisms and residues thereof, such as endotoxins[2] (Winkel et al, 2014). In the Netherlands, specific research has therefore been carried out in recent years into the health of residents living in the vicinity of livestock farms exposed to these particles. This concerned successively the research projects "Intensive Livestock Farming and Health" (Heederik and IJzermans, 2011), "Livestock Farming and Health Residents" (Maassen et al., 2016), "Livestock Farming and Health Residents II" (Hagenaars et al., 2017), "Livestock Farming and Health Local Residents III (IJzermans et al., 2018) and" Risk Modeling Livestock Farming and Health "(Heederik et al, 2019). These studies show that exposure to stable dust and the endotoxin in it is associated with less atopy (sensitivity to allergy). On the other hand, exposure is associated with more complaints and more use of medicines in residents with COPD[3], more pneumonia, more respiratory complaints and decreased lung function.

1.2 Background

In the Food valley region, a region of eight municipalities[4] with a combined population of approximately 350,000, relatively high concentrations of particulate matter, ammonia (NH_3) and odor occur due to the presence of many livestock farms. Following the results of the studies into the effects of livestock farms on the health of local residents, agreements have been made in the Food Valley Region between regional authorities and the livestock sector to increase the contribution of

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[1] One micrometer (µm) is equal to one thousandth of a millimeter, 10 µm is equal to one hundredth of a millimeter.

[2] Endotoxins are cell wall parts of Gram-negative bacteria that are highly inflammatory.

[3] COPD: Chronic Obstructive Pulmonary Disease = Chronic Obstructive Lung Disease.

[4] The eight municipalities in the Food valley region are: Barneveld, Ede, Nijkerk, Rhenen, Renswoude, Scherpenzeel, Veenendaal and Wageningen.

livestock farming to reduce the air quality in the region. This collaboration is laid down in the Manifesto Healthy Living Environment for Livestock Farming (GLV). The agreements in the Manifesto roughly comprise two tracks:

- Administrative: optimization / utilization of opportunities within licensing, scenario calculations, coordination, and amendment of central government regulations.

- Practice: collecting and sharing knowledge about emission reductions from techniques and barn systems, promoting and facilitating innovations, testing and improving measurement methods and strategies.

Within the 'practical route', the Practice Center for Emission Reduction Livestock Farming (PEV) has been established with which those involved in the GLV Manifesto want to accelerate the development and practice of feasible and affordable emission-reducing techniques and housing systems that are not yet available in the Emission Factors List. particulate matter for livestock farming (National government, 2018).

Although the PEV wants to focus on reducing emissions of all forms of air pollution from stables, it was initially decided to focus on techniques that reduce the emission of particulate matter. To this end, a process was started in which innovative suppliers of techniques could register their system with relevant information about, among other things, the operating principle, the expected reduction percentage and the annual costs for livestock farmers. Via a selection procedure, eight techniques have been selected that have been installed on livestock farms to determine their effect on the emission of PM10. In this report the results of the measurements are presented for one of these techniques.

1.3 Scope and purpose

This measurement report contains the results of the emission measurements made in the pilot with the HD ionization lamps from Freshlight, installed in a laying hen house. Emission-reducing techniques for animal housing are normally tested according to the measurement protocol as drawn up in the Netherlands (Ogink et al., 2011) and in the international VERA collective (VERA, 2018a). The pilots deviated from these protocols on several points to obtain a good first impression of the reduction potential of a technique with limited efforts and costs. The uncertainties associated with the omissions regarding the protocols are assessed in the discussion of this report. Based on this measurement report, the technique can be included in national or regional regulations with a (provisional) reduction percentage for particulate matter. Entrepreneurs in the livestock sector can then use this technique on their farm to reduce the burden on the environment with stable dust.

1.4 Structure of the report

As usual in a measurement report, Chapter 2 discusses the materials and methods used. First the technique on which the measurements are aimed is described, together with the operating principle. This is followed by a brief description of the shed in which the technique has been applied. Finally, the measurement methods used, and the measurement strategy are described and the processing of the measurement data. In chapter 3 the results of the measurements are presented, followed in chapter 4 with a discussion about the aspects that may have influenced the technique and about the extent to which the results can be used for inclusion in (national) regulations. The conclusion based on the discussion then follows in Chapter 5.

2 Material and methods

2.1 Description of technique and operating principle

Three rows with 16 HD ionization lamps each hung from the roof of the barn. The HD ionization lamps consist of an LED TL and an ionization part. The ionization part produces 300 * 10_6 ions per second with 12 carbon brushes. The ionisation part consumes 2.4 watts. In this laying hen house, there were 48 lamps with an ionisation part, the ion production was 16.8 * 10_6 ions per second per m² floor surface. According to the supplier, the working principle consists of changing the electrical charge of dust particles so that they bind to other dust particles and water molecules in the air. This makes the dust particles heavier; these heavier particles settle on the ground. The system does not use ventilation or recirculation (Freshlight, 2019). Figure 2.1-A shows a photo of an ionization lamp. Figure 2.1-B shows the technique as applied in the test stable in which the measurements were taken.

Appendix 6 contains a draft description, in accordance with the format of the BWL descriptions for reducing techniques. These are the most important elements that a shed equipped with this technology must meet to achieve a comparable effect on the dust emission.

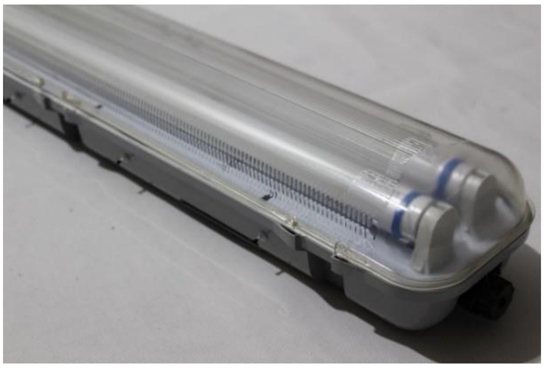

Figure 2.1-A *A Photo of the HD ionization lamp.*

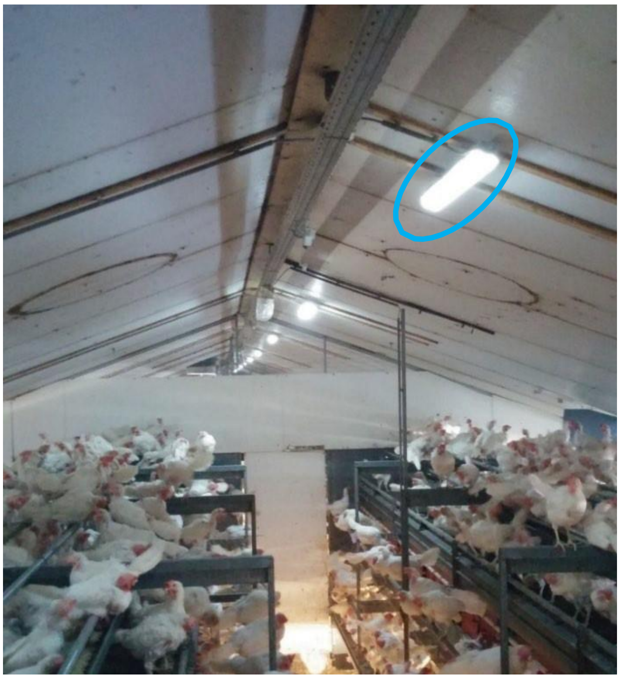

Figure 2.1-B *The HD ionization lamps in the shed where the measurements were taken. In the photo, one ionization lamp is circled in blue.*

2.2 Description of the barn and operating situation

The measurements were carried out in a house for laying hens. 12,000 organic laying hens were kept in the house, divided over four compartments (see also figure 2.1-B). The chickens were housed in two system rows with corresponding three litter passages. Four ridge fans (one in each compartment) were used for the ventilation of the barn. The air entered the house through inlets in both side walls. In the house there were three rows with 16 HD ionization lamps each, one row through the middle of the house and two on the outside to illuminate the entire house (see figure 2.1-B). On the north side, the barn has an indoor covered run-out from which the laying hens could also go outside. It was taken out of service during the measurements. Appendix 1 contains an overview of the main characteristics of the barn and some management aspects, together with some photos, a barn plan and an overview photo of the company. This overview photo shows that there is another house on the farm in a southerly direction compared to the measured house, this is a rearing laying hen house. Other agricultural companies are present in the further vicinity, including poultry farms.

2.3 Measurement strategy

Emission-reducing techniques for animal housing are normally tested according to the measurement protocol as drawn up in the Netherlands (Ogink et al., 2011) and in the international VERA collective (VERA, 2018a). These protocols prescribe the following, among other things:

- a technique must be tested at two company locations in order to include variation in the performance of the technique between companies (due to variety, management, nutrition, etc.) in the final reduction percentage;
- the measurements must take place in a trial barn versus an identical reference barn on the same farm (a "case-control" strategy) or after versus before an end-of-pipe technique such as a filter;
- Six 24-hour measurements must be carried out per company location (12 in total). At least four of these measurements per business location and ten in total must yield reliable results. By taking measurements over 24 hours, all variation that occurs within a day is included in the results. The measurements must be spread over the calendar year and the production period of the animals in order to also include variations due to seasons and production stages of animals in the results;
- the emission consists of the product of the ventilation flow times the concentration of a pollutant. The protocol prescribes a number of scientifically valid measurement methods for both the measurement of the ventilation flow and the measurement of concentrations. For poultry houses where several fans are present (which hinders the use of measuring fans), the CO^2 balance method is a valid method to determine the ventilation flow rate. For particulate matter, the Dutch particulate matter protocol prescribes a gravimetric method that is suitable for use in a dusty stable environment;
- the stables measured must comply with agricultural preconditions, see Appendix 2. This includes which operating parameters must be recorded and reported when the measurements are carried out, in order to be able to verify afterwards whether the measurements were taken under representative conditions.

In view of the great need for innovative techniques for particulate matter reduction in poultry farming, the aim of the particulate matter pilots in the Foodvalley region is to quickly gain insight into the perspective and the reduction of such techniques in a relatively cheap and simple manner. That is why in the pilots a number of deliberate omissions have been made with regard to the methodology. These can be summarized as follows:

a. the average emission reduction is determined by a measurement series of six measurements at one company location instead of two measurement series of a total of twelve measurements at two company locations, as prescribed by the measurement protocol;
b. Measurements were not taken in a physical test house and a physical control house but measured according to a "case-control over time" strategy. A technique is then installed in a test stable where the reduction percentage is determined via measurements during on-days versus off-days;

c. the concentrations and emissions of particulate matter (PM_{10}) were determined with DustTraks (a light scattering method) instead of a gravimetric measurement method;
d. the ventilation flow is determined on the basis of the CO_2 balance method based on measurements of CO_2 in the house (in accordance with the measurement protocol) but with a fixed (unmeasured) background value for CO_2 in the outside air;
e. the background concentrations of particulate matter (PM_{10}) have not been measured; for this, background concentrations have been used from the closest measuring station of the Air Measurement Network (RIVM, 2019).

A total of six measurements were performed, all of which yielded useful results. Measurements were carried out for approx. 24 hours. During the study period, the reducing technique in the barn was normally "on". During the first measurements, measurements were first taken for 24 hours with the technology on, after which the technology was set to "off" at the end of the measurement. After a stabilization period of at least 24 hours, measurements were taken with the technique off for 24 hours. At a later stage, the case and control days were reversed. The poultry farmer switched off the technique 24 hours before the start of the "out" measurement. After these 24 hours, the "off" measurement was started and the poultry farmer switched the technique back on after 24 hours, whereby the measurement continued and switched to the "on" measurement. The "on" measurement was then continued for at least 25 hours, with the first hour being seen as a stabilization period and not included in the processing of the data. According to the supplier, an hour of stabilization period between the off and on measurement is sufficient to measure the effect of the ionization lamps. The reason for this change in the measurement strategy was that in the first measurements there were large differences in outdoor climate between case and control days, which may translate into different ventilation rates and thus a less pure basis for comparison between the two days. In order to attribute a reduction of the emission as purely as possible to the effect of the reducing technique, the measurement days have been chosen closer together; with a smaller chance of large differences in outdoor climate.

During the aforementioned measurement days, the concentrations of particulate matter (PM10) and carbon dioxide (CO_2) were measured, as well as the temperature and relative humidity (RH). The ammonia concentration was measured indicatively on each measurement day using gas detection tubes (Kitagawa). There are no concentrations of particulate matter or values of temperature and RH measured in the outside air. For these values, the closest KNMI monitoring stations (for temperature and RH, location: de Bilt) and RIVM (for PM10, location: Wekerom-Riemterdijk) were used for the same period as the measurement periods. A fixed value of 400 ppm has been taken for the concentration of CO_2 in the outside air.

Figure 2.2 *Location of the measurement of the concentrations in the house (circled in blue). The blue arrow indicates the air flow into the ventilation duct, outwards.*

To determine the concentrations in the outgoing airflow, a position was chosen as close as possible to the fans that take care of the removal of the barn air, such that the air velocity remained below 2 m / s to avoid non-isokinetic conditions (i.e. conditions where the air velocity in the house and that of the sample flow are too much out of step and larger particles are under- or oversampled). Figure 2.2 shows the situation in the measured barn of the measurement position in relation to the fans. In Appendix 1, the measuring point in the barn is circled in blue.

2.4 Measurement methods

A description of the maintenance and calibrations of the instruments below can be found in Appendix 4.

2.4.1 Particulate matter (PM_{10})

The concentration of particulate matter (PM10; mg / m3) was measured in duplicate with a DustTrak device (DustTrakTM Aerosol Monitor, models 8520 and 8530, TSI Inc., Shoreview, USA; see figure 2.3 for both models). The PM10 concentration was measured every second and logged as two-minute averages in the DustTraks memory. The DustTraks systematically underestimates the true concentration (as determined according to CEN-EN 12341; Winkel et al., 2015a; Cambra-López et al., 2013). Therefore, the concentrations, of both test and reference periods, have been corrected with a correction factor. For the measurements performed with model 8520, this is the factor 2.14 as published by Winkel et al. (2015a) and Cambra-López et al. (2013). For the measurements performed with model 8530, this is the factor 2.53 determined by WLR in the same way as was done in Winkel et al. (2015a). The results of the measurements underlying this correction factor are shown in Appendix 3.

Figure 2.3 *DustTrak models used for measuring PM10. Left model 8520, right model 8530.*

2.4.2 Ventilation flow rate

TThe concentration of carbon dioxide (CO2) was measured to determine the ventilation flow rate. The ventilation flow has been determined using the CO2 balance method. The CO2 concentration in the outgoing barn air was measured using a Testo CO2 meter (Testo BV; Almere, The Netherlands; type 435, with IAQ probe for CO2) or a Vaisala CO2 sensor (Vaisala; Vantaa, Finland; CARBOCAP ® Carbon Dioxide Probe GMP252; type with measuring range 0-5000 ppm).

2.4.3 Temperature and relative humidity

To record the measurement conditions, temperature and relative humidity were measured with a combined logger (Escort iLog; Askey dataloggers; Leiderdorp, the Netherlands).

2.4.4 Production data

On every second day of the measurements, the following information was taken from the loft card:
- number of mounted and present animals;
- if possible: average animal weight (possibly read value for the relevant production stage from the production guide of the animal brand);
- feed consumption of the animals;
- water consumption of the animals;
- laying percentage;
- egg weight;
- failure;
- possible administration of medication or additives.

2.5 Data processing and analysis

2.5.1 Calculation of ventilation flow

The CO_2 balance method was used to calculate the ventilation flow per individual measurement day. This method is based on the CIGR calculation rules for determining the CO_2 production of the animals (CIGR, 2002; Pedersen et al., 2008). To do this, the heat production of the laying hens is first calculated as follows:

$$\Phi_{tot} = 6.8\, m^{0.75} + 25 Y_2$$

at which:
- Φ_{tot} = total heat production per animal in W;
- m = weight of the animal in kg
- Y_2 = egg production in kg/day.

The CO_2 production was then calculated using the following formula:

$$CO_2 - production = \Phi_{tot} * 0.185$$

at which:
- CO_2-production = production of CO_2 in m^3/hour per animal;
- 0.185 = value for CO_2-production per kW in m^3/hour per animal.

The ventilation flow rate was then calculated based on the following formula:

$$Q = \frac{CO_2 - production}{([CO_2]_{barn} - [CO_2]_{outside}) * 10^{-6}}$$

at which:
- Q = ventilation flow rate in m^3/hour per animal;
- $[CO_2]_{barn}$ = CO_2 concentration in parts per million (ppm) measured at the emission point of the barn;
- $[CO_2]_{outside}$ = fixed value for the concentration of CO_2 of 400 ppm.

2.5.2 Calculation of particulate matter emission

The emission of PM_{10} was determined per individual measurement day, i.e. both for the "reference days" and the "trial days" within the trial house, based on the following formula:

$$E = Q * ([PM_{10}]_{barn} - [PM_{10}]_{outside}) * 10^{-6} * 24 * 365$$

at which:
- E = emission of PM_{10} in g/year per animal present;
- Q = ventilation flow rate in m^3/hour per animal;
- $[PM_{10}]_{barn}$ = the concentration of PM_{10} in µg/m^3, measured near the emission point of the barn;

- $[PM_{10}]_{outside}$ = de concentration of PM_{10} in µg/m^3, measured by the nearest measuring station of the National Air Quality Monitoring Network for the same period;
- 10^{-6} = conversion factor from µg to g;
- 24 = conversion factor from hour to day;
- 365 = conversion factor from day to year.

The above calculation does not consider the vacancy between production periods. This is necessary when calculating an absolute emission factor, but not in this situation for calculating a reduction percentage.

2.5.3 Calculation of the final reduction percentage of particulate matter emission with bandwidth

The following situation occurred in the pilot:
- laying hens with a stable emission pattern;
- measurement days that have been chosen in a balanced manner over the production period and the year.

In this situation, the final reduction percentage has been calculated on the emissions. By first averaging the emissions from case days and control days and then calculating a final reduction percentage over those two average emission figures, the individual reduction percentages are weighted in proportion to their contribution to the total emission.

To gain some insight into the precision with which the final reduction percentage obtained was determined, a number of confidence intervals have been calculated for this figure. An x% confidence interval is a combination of a lower limit and an upper limit for which it is certain for x% that the average falls within it. The reduction percentages of the individual measurements were used for this. Assuming statistical independence and normality, the confidence interval is equal to the mean ± $t_{(v=n-1;\ \alpha)}$*SE, where t is the value from the Student distribution for v degrees of freedom, n observations and an unreliability threshold α and SE are the standard error (calculated as the standard deviation divided by the square root of the number of observations).

2.5.4 Statistical analyzes

Differences between case and control days for the variables directly or indirectly related to the emission process were tested for significance by means of paired t-tests. This concerns the factors:
- temperature in the house;
- relative humidity in the house;
- CO2 concentration in the house;
- ventilation flow rate;
- particulate matter concentration in the house, and;
- particulate matter emission.

The first four variables mentioned have been tested on both sides. The last two variables mentioned were tested unilaterally, based on the research hypothesis of higher values on control days.

The comparability of the ventilation flow rate on case days versus that on control days was explored using Simple Linear Regression. The ventilation flow rate on case days is taken as a Y variable and the ventilation flow rate on control days as an x variable. Ideally, a Y = x or 1: 1 relationship is created between the two variables with a line segment through the origin at an angle of 45 degrees upwards. It was tested whether the slope deviates significantly from 1 (standard regression tests for deviations from zero).

Relationships between the reduction percentage and possible influencing factors (particulate matter concentration, ventilation flow rate) on the effectiveness of the technique were explored using Simple Linear Regression. Here an effect of the influence factor (x-variable) on the reduction percentage (Y-variable) is explored by testing whether the slope deviates significantly from zero.

For the analyzes, the pairs of observations were considered statistically independent. Differences or relationships were considered statistically significant at a P value <0.05 and trended at a P value between 0.05 and 0.10. All analyzes were performed using the GenStat statistical program (VSN, 2019).

3 Results

3.1 Measurement conditions

The Dutch measurement protocol for particulate matter (Ogink et al., 2011) prescribes that six measurements must be taken per company location. The measurements must be taken evenly over a year. Figure 3.1 shows how the measurements at the location were actually distributed. At least 80% of the measurements must yield reliable results. The measurements were carried out in a balanced manner over the production period.

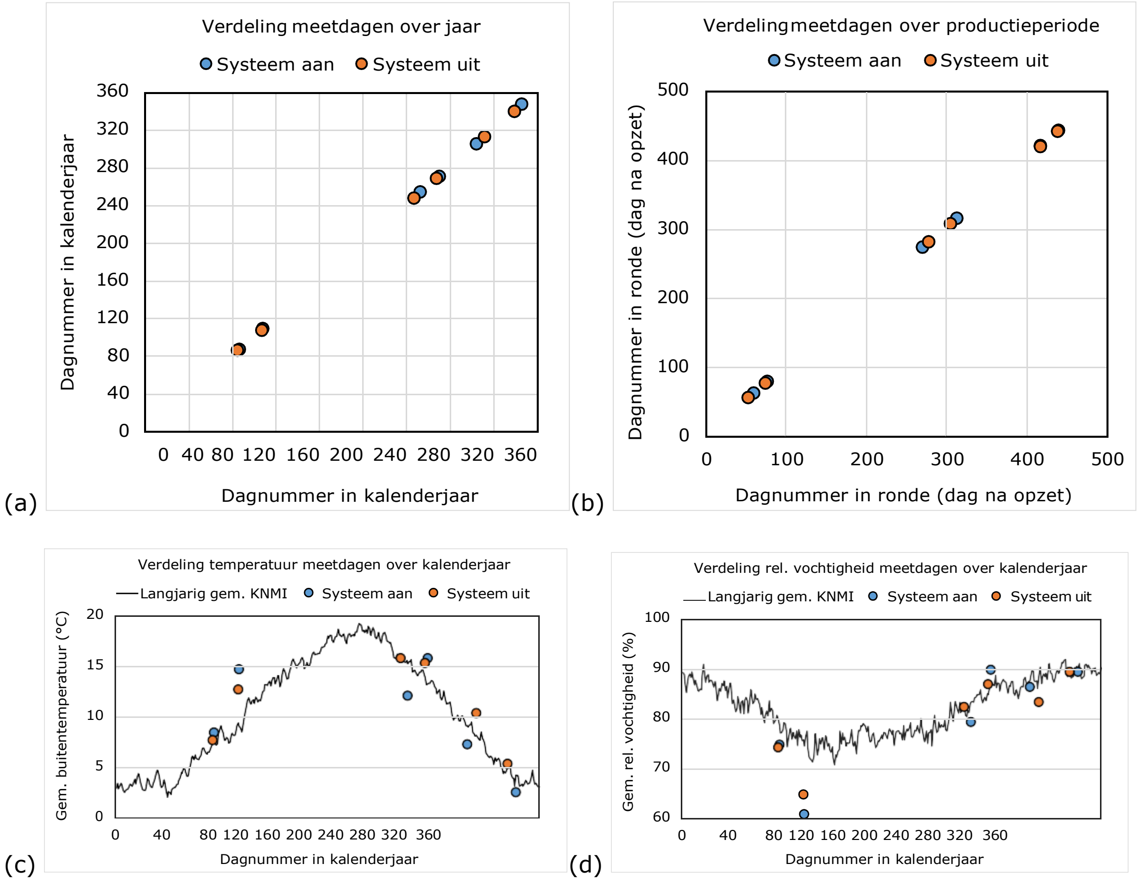

Figure 3.1 *Distribution of the measurements over the year (a) and production period (b) and in comparison, with the outside temperature (c) and relative humidity (d) according to the average values measured over 1981 to 2010 from the KNMI station. Bilt (shown as a line).*

A total of six measurements were carried out in the period from October 2018 to September 2019. All measurements gave reliable results.

The average day number of the days on which the measurements were taken is 226 (target: approximately 183). The measurements are not completely evenly distributed over the year. Two measurements take place in the spring and four measurements in the autumn. No measurements were taken in the winter and summer and fewer measurements in the first half of the year. The reason for this division is, among other things, the duration of the project, the inability to deploy measurement technicians due to illness, threat of avian influenza and the Fipronil crisis (company visits were not possible in some periods due to the latter two reasons).

Table 1 shows, among other things, the dates on which the measurements were carried out with the relevant technical results and climate conditions (outside and inside the barn). The technical results of the animals (water intake, feed intake, water / feed ratio, production, and mortality) were almost all within the standards of the breed set by the breeding group and the agricultural conditions. The higher dropout percentage compared to the agricultural conditions is explained by the fact that measurements were taken with organic laying hens. The failure rate for this production method is normally higher than for regular hens. Furthermore, there have been no deviations from the standard business management.

The data from the measuring station in De Bilt was used for the climate data for the outside air (temperature and RH). The average outside temperature was 10.0 ° C for the measurement days with the technology on versus 11.0 ° C for the measurement days with the technology off (long-term average KNMI: 10.2 ° C). For the RH this was 80% on both measurement days (long-term average KNMI: 82%). The average outside temperature during the measurements was therefore only 0.2 ° C lower and 0.8 ° C higher than the long-term average for respectively measurement days with the technology on and off. This is mainly because measurements were carried out in the spring and autumn. The average RH during the measurement days was only two percentage points below the long-term average.

The average temperature in the house was 21.9 ° C for the measurement days with the technique on versus 23.1 ° C for the measurement days with the technique off. The statistical analysis showed a trend-wise lower temperature for measurement days with the technique on ($P = 0.09$). The average relative humidity in the house was 58.3% for the measurement days with the technique on versus 58.9% for the measurement days with the technique off. The statistical analysis showed this difference not statistically significant ($P = 0.84$). Apparently, the measurement days have been slightly warmer on average with the technology. The difference is statistically only slightly trend-based, so this is probably a coincidence.

The values of the indicative NH3 measurements are not included in table 3.1. They varied within the normal values for houses with laying hens and give no reason to analyze a relationship with the HD ionization lamps.

Chart 1 *Data on which the measurements were carried out with day number in the year and day number in the production cycle, relevant technical results, and the climate conditions (outside climate and in the house).*

Variable [unit]	MEASUREMENT 1		MEASUREMENT 2		MEASUREMENT 3		MEASUREMENT 4		MEASUREMENT 5		MEASUREMENT 6	
	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON
General												
Date of measurement start [dd-mm-yyyy]	7-11-2018	30-10-2018	4-12-2018	11-12-2018	25-3-2019	26-3-2019	16-4-2019	17-4-2019	3-9-2019	9-9-2019	24-9-2019	26-9-2019
Time to start measurement [hh: mm]	14:10	11:00	12:15	10:30	10:58	11:16	9:15	11:16	12:30	12:30	12:00	12:00
Date end of measurement [dd-mm-yyyy]	8-11-2018	31-10-2018	5-12-2018	12-12-2018	26-3-2019	27-3-2019	17-4-2019	18-4-2019	4-9-2019	10-9-2019	25-9-2019	27-9-2019
Time end of measurement [hh: mm]	14:10	11:00	12:15	10:30	10:58	11:16	9:15	11:16	12:30	12:30	12:00	12:00
Day number in year [#]	311	303	338	345	84	85	106	107	246	252	267	269
Production indicators												
Set up date animals [dd-mm-yyyy]	2-2-2018	2-2-2018	2-2-2018	2-2-2018	2-2-2018	2-2-2018	2-2-2018	2-2-2018	15-3-2019	15-3-2019	15-3-2019	15-3-2019
Breed	Nick Chick		Nick Chick		Nick Chick		Nick Chick		Hyline Brown		Hyline Brown	
Day number in production round	278	270	305	312	416	417	438	439	53	59	74	76
Number of animals placed	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
Number of animals present	11520	11560	11420	11380	10490	10490	10275	10275	11966	11966	11952	11952
Failure cumulative [%]	4,00	3,67	4,83	5,17	12,58	12,58	14,38	14,38	0,28	0,28	0,40	0,40
Animal weight [g]	1700	1700	1700	1700	1800	1800	1800	1800	1800	1800	1800	1800
Feed intake [g / animal per day]	129	129	129	129	129	129	129	129	124	124	125	125
Water intake [mL / animal per day]	200	200	200	200	214	214	214	214	214	214	200	200
Water / feed ratio	1,56	1,56	1,56	1,56	1,66	1,66	1,66	1,66	1,72	1,72	1,60	2
Laying percentage	95,0	96,0	94,0	93,2	84,0	84,0	83,0	83,0	95,0	95,0	95,0	95
Average egg weight	64,1	63,8	64,5	66,0	66,8	66,8	67,0	67,0	53,0	53,0	53,0	53,0
Outside air conditions												
Avg. temperature (KNMI) [° C]	10,2	7,1	5,2	2,4	7,5	8,3	12,5	14,5	15,6	11,9	15,2	15,6
Avg. relative humidity (KNMI) [%]	83	86	89	89	74	75	65	61	82	79	87	90
Wind direction (KNMI)	ZZO,Z	Z,ZZO	W,ZZO	WNW,O	NW,WNW	WNW,WNW	O,OZO	OZO,O	ZW,ZZW	ZW,W	ZZO,Z	ZZW,ZZW
Background PM10 (LML) [µg / m3]	13,0	7,2	13,6	17,5	17,7	20,8	24,9	23,6	12,2	12,6	12,7	13,3
Background PM2.5 (LML) [µg / m3]	5,7	6,6	8,5	10,0	7,3	10,7	16,2	14,7	6,3	8,1	4,8	4,9
Stable air and ventilation												
Air temperature [° C]	23,0	20,2	23,5	22,4	*not available*	*not available*	24,0	22,6	23,0	22,7	21,7	21,7
Relative air humidity [%]	58,0	61,9	58,2	56,3			39,5	46,4	63,3	57,1	75,5	70,0
CO2 concentration [ppm]	1539	1717	2428	2335	2018	1749	1310	1183	1076	1480	1021	1045
Ventilation flow rate house [m3 / h per animal]	1,89	1,64	1,06	1,11	1,37	1,64	2,43	2,83	3,24	2,03	3,52	3,39
Fine dust concentrations and emissions												
Avg. concentration of PM10 [µg / m3]	7870	6421	10017	4327	11556	4754	7028	3318	3956	5223	3822	2087
Concentration reduction PM10 abs. [Mg / m3]	1450		5690		6802		3710		-1267		1735	
Concentration reduction PM10 rel. [%]	18		57		59		53		-32		45	
Avg. emission of PM10 barn [g / animal per year]	130	92	93	42	138	68	149	82	112	92	118	62
Emission reduction PM10 abs. [G / animal per year]	38		51		70		68		19		56	
Emission reduction PM10 rel. [%]	**29**		**55**		**51**		**45**		**17**		**48**	

3.2 CO_2-concentration and ventilation flow

Chart 1 shows the measured CO2 concentrations. The average CO2 concentration in the house was 1585 ppm for the measurement days with the technology on, versus 1565 ppm for the measurement days with the technology off. The statistical analysis showed that this difference was not statistically significant (P = 0.851). Based on the ventilation flow rates, among other things, are calculated for the CO2 concentrations in the house shown in table 1. In figure 3.2 these are shown in relation to the day number in a calendar year. The ventilation flow shows a normal course over a calendar year: increasing in the spring and decreasing in the autumn. However, days with flow rates at the top of the range (above 4 m3 / hour per animal) are missing from the dataset. A comparison with the development of the ventilation flow rate with other measurement reports is difficult, there are no measurement reports available with measurements on the same animals and housing.

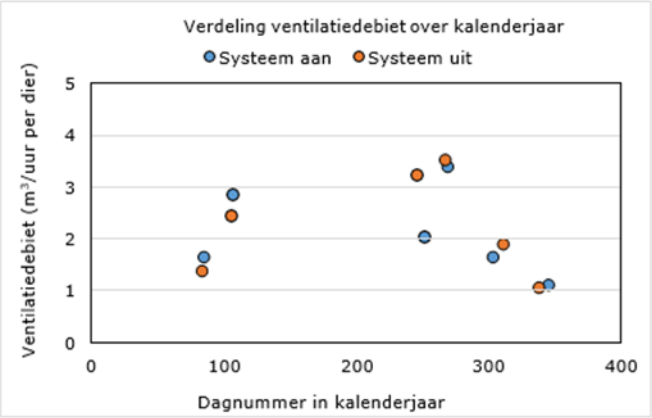

Figure 3.2 *Distribution of the ventilation flow over the calendar year.*

The mean ventilation flow rate (± standard deviation) was 2.1 (± 0.9) m³ / hour per animal for measurement days with the technique on versus 2.3 (± 1.0) m3 / hour per animal for measurement days with the technique off. The statistical analysis showed this difference not statistically significant (*P* = 0.561).

Figure 3.3 shows a further comparison of the ventilation flow rate between measurement days with the technique on versus measurement days with the technique off by means of simple linear regression analysis.

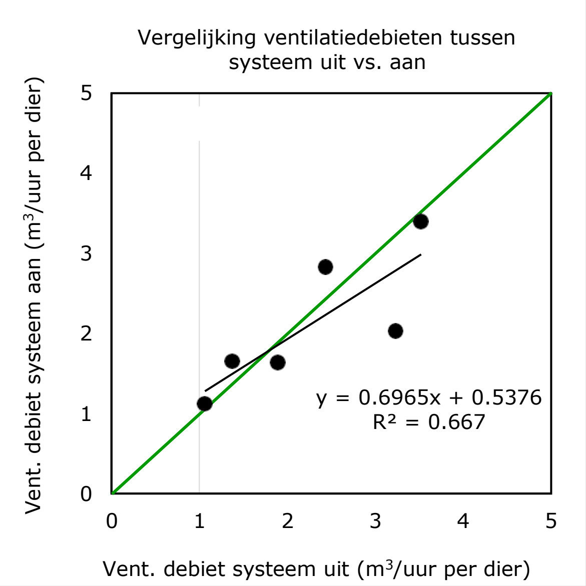

Figure 3.3 *Comparison of the ventilation flow between measurement days with the technology on versus measurement days with the technology off.*

significantly different from zero (i.e. due to the origin; P = 0.419). This analysis also shows that the ventilation flow rates were very similar between days with the system on and days with the system off. This means that there was a pure basis for comparison in the measurement strategy regarding the ventilation flow rate.

3.3 Concentration, emission en reduction of PM_{10}

The values from the RIVM measuring station in Wekerom were used to correct the emission from the barn with the background concentration. The concentrations and emissions of PM10 on measurement days with the technology on and measurement days with the technology off are shown in figure 3.4. The figure shows that the concentrations decrease, and the emissions increase with increasing temperatures. The concentration and emission are probably dependent on the ventilation flow. The figure shows that the emissions on the days with the technology on were lower in all cases than on the days with the technology off. This is not the case once for the concentrations, probably due to a larger difference in ventilation flow rate on this measurement day.

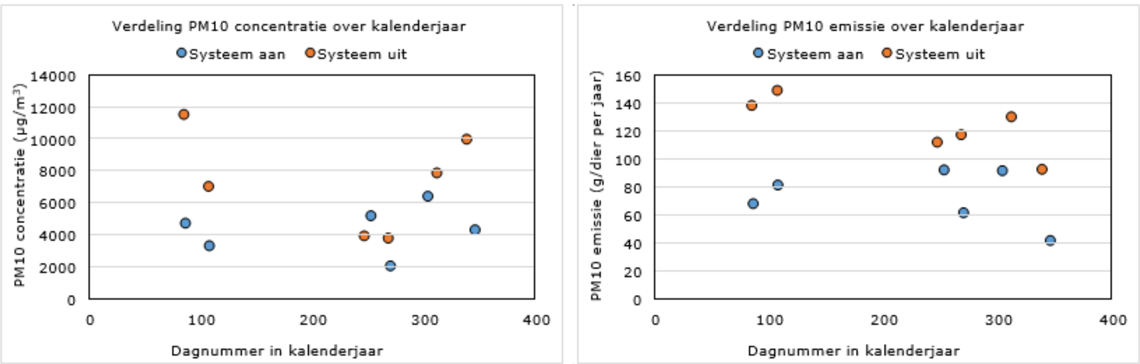

Figure 3.4 *PM_{10} concentrations (left) and PM_{10} emissions (right) on the measurement days with the technology on and measurement days with the technology off.*

The mean (± standard deviation) PM_{10} concentration in the barn was 4355 (± 1510) µg/m^3 for the measurement days with the technique on versus 7375 (± 3135) µg/m^3 for the measurement days with the technique off. The statistical analysis showed this difference statistically significant (P=0,028).

The average PM_{10} emission from the house (calculated as described in sections 2.5.2 and 2.5.3) was 73.0 g / animal per year for the measurement days with the technique on versus 123.4 g / animal per year for the measurement days with the technique. The statistical analysis showed the difference in emissions statistically significant (P <0.001). Based on these values, the final reduction percentage of the technique is 41%. The emission levels are representative of those that normally occur in laying hen houses (Winkel et al., 2015b).

Figure 3.5 shows the reduction percentages as a function of the day number in the production round, the ventilation flow rate and the PM_{10} concentration in the house. Because these only concerns six observations from one location, this exploration of influencing factors on the effectiveness of the technique must be interpreted with caution. The general picture from figure 3.5 is that of a reduction percentage which is not affected during the production period, due to higher dust concentrations and the ventilation flow rate. Of these variables, the ventilation flow rate does not have a statistically significant influence on the reduction percentage (P = 0.981), and no statistically significant relationship has been found with the PM_{10} concentration (P = 0.244). A decreasing effectiveness of ionization systems in poultry houses until the next cleaning moment has not been found with this system. This contrasts with a negative ionization system from the company Inter Continental (Ysselsteyn, the Netherlands), experimentally investigated in an experimental laying hen house (Winkel et al., 2009) and in contrast to a positive ionization system from the company ENS Clean Air (Cuijk, the Netherlands).) tested in two laying hen houses (Winkel et al., 2013).

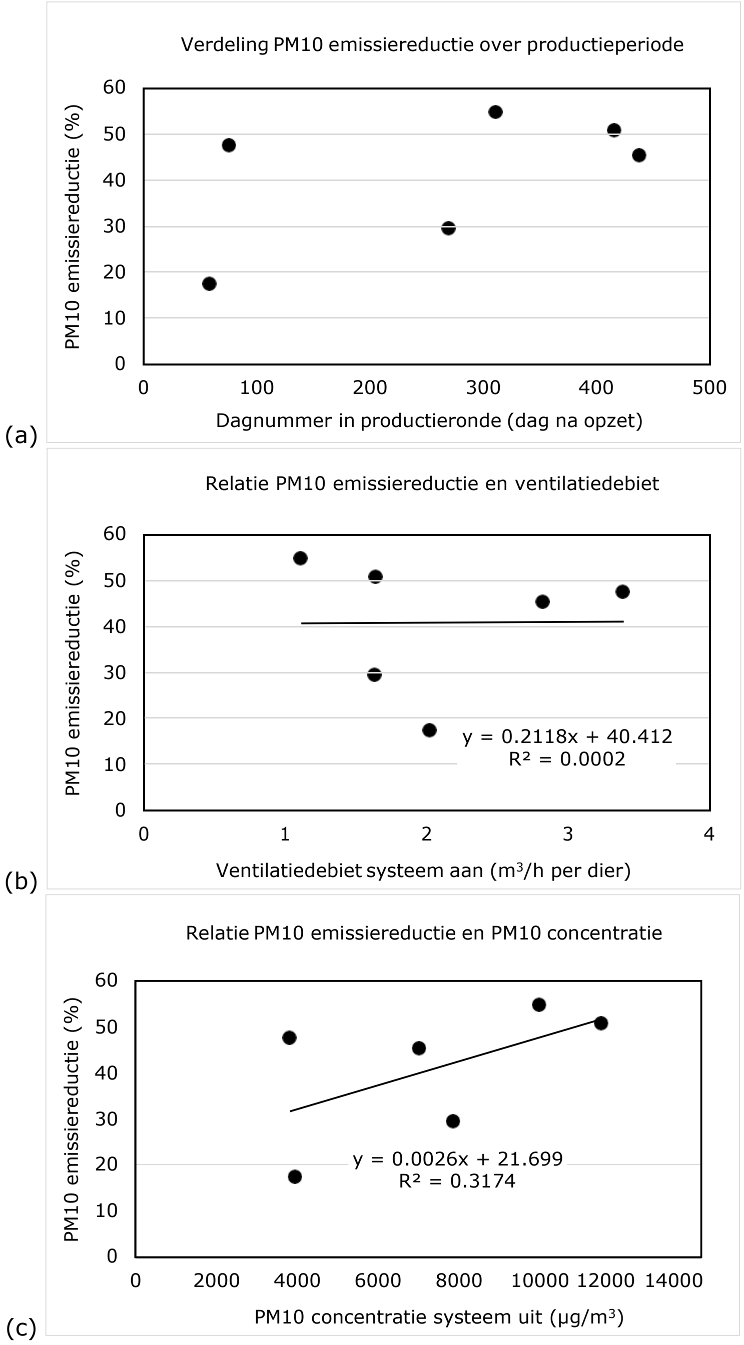

Figure 3.5 *The reduction percentage for PM10 as a function of (a) day number in the production round, (b) the ventilation flow rate and (c) the PM10 concentration in the barn.*

4 Discussion

Regarding the results of the measurements and their translation into a reduction percentage, the following points of discussion should be considered. The assessment of these points of discussion ultimately leads to the conclusion expressed in chapter 5.

For the application of emission-reducing techniques in stables in the context of obtaining an environmental permit, these techniques must be included in the official "List of Emission Factors for Particulate Matter for Livestock Farming" as it is regularly updated and published on the website of the National Government (Rijksoverheid , 2018). Inclusion of the technology in the list with a specific reduction percentage takes place after the supplier of the technology has applied with a measurement report to the Netherlands Enterprise Agency (RVO). Although not laid down by law (as is the case with ammonia, by the way), it is common for the measurement report and the methods followed therein to be in accordance with the measurement protocol "Protocol for the measurement of particulate matter emissions from housing systems in livestock farming 2010" as published by Ogink et al. al. (2011). To assess applications, RVO asks technical advice from the Technical Advice Pool (TAP). This is a pool of experts who work for various companies and organizations. The assessment process is based on the assessment-review principle. This means that at least two experts will assess the application. This to arrive at a fully-fledged final advice. Based on this final advice, the State Secretary for Infrastructure and Water Management determines the ultimate reduction percentage.

In view of the great need for innovative techniques for particulate matter reduction in poultry farming, the aim of the particulate matter pilots in the Food valley region is to quickly gain insight into the perspective and the reduction of such techniques in a relatively cheap and simple manner. That is why in the pilots several deliberate omissions have been made regarding the methodology. These can be summarized as follows:

a. the average emission reduction is determined by a measurement series of six measurements at one company location instead of two measurement series of a total of twelve measurements at two company locations, as prescribed by the measurement protocol;
b. Measurements were not taken in a physical test house and a physical control house but measured according to a "case-control over time" strategy. A technique is then installed in a test stable where the reduction percentage is determined via measurements during on-days versus off-days
c. the concentrations and emissions of particulate matter (PM_{10}) were determined with DustTraks (a light scattering method) instead of a gravimetric measurement method;
d. the ventilation flow is determined based on the CO_2 balance method based on measurements of CO_2 in the house (in accordance with the measurement protocol), but with a fixed (unmeasured) background value for CO_2 in the outside air.
e. the background concentrations of particulate matter (PM_{10}) have not been measured, for this background concentrations have been used from the nearest air monitoring station of the Air Measurement Network (RIVM, 2019).

Prior to the particulate matter pilots in the Foodvalley region, these omissions were explained and discussed with representatives of the Ministry of Infrastructure and the Environment and RVO. It has been agreed that the measurement reports from the particulate matter pilots may be submitted to RVO and will be submitted for assessment and advice by the TAP. However, it was also agreed that in the discussion of the measurement report an analysis and interpretation will take place of the extra uncertainty that the omissions in the particulate matter pilots entail. Based on this analysis and interpretation and based on the assessment and advice by the TAP, an uncertainty margin can be deducted from the result obtained from a particulate matter pilot when determining the reduction percentage. If a supplier wants to replace the reduction percentage with uncertainty margin with a definitive (i.e. more reliable and probably higher) reduction percentage, a measurement report of a second measurement series at a second company location must be submitted to RVO. The table below shows the lower limits of the reduction percentages for a number of confidence intervals and the probability that the reduction is higher than this lower limit. This compared to the average reduction percentage of 41%.

Chart 2 *Different confidence intervals with the probability that the reduction percentage is higher than the lower limit and the lower limit of the reduction percentage.*

Confidence Interval	Lower Limit reduction percentage	% Probability that reduction is higher than lower limit
95%	25,7%	**97,5%**
90%	29,0%	**95%**
80%	32,1%	**90%**
70%	34,0%	**85%**
60%	35,4%	**80%**
50%	36,6%	**75%**

The uncertainty associated with omissions a, b, c, d and e is discussed below.

a. One instead of two company locations and six instead of 12 measurements
According to the measurement protocols used, a case-control measurement strategy must be measured at at least two business locations to include variation in the performance of the technology between different houses in the final reduction percentage. This report shows the results of measurements at one company location. At this location, the technique may - for whatever reason - have systematically performed better or worse than the actual average performance as it could theoretically be obtained by measuring the technique at a very large number of locations. Some insight into the inter-farm variation of ionization techniques can be obtained from the measurement reports of a negative ionization system from the company Inter Continental (Ysselsteyn, the Netherlands) tested on two broiler farms and a positive ionization system from the company ENS Clean Air (Cuijk, the Netherlands) tested in two laying hen houses (both measurement reports have been published as a scientific article containing individual reduction percentages per location by Winkel et al., (2016)). Attn. the first ionization technique, the average PM_{10} reduction percentage was 47% with reduction percentages per company location of 46% on average for company 1 and 49% for company 2. in the second ionization technique, the average PM_{10} reduction percentage was 6% with reduction percentages per company location of an average of 12% for company 1 and 4% for company 2. These two ionisation techniques therefore show a comparable picture (small inter-company variation) in both company locations. For the two techniques, it has been demonstrated on the smallest possible scale (2 business locations) that the reduction percentage is reproducible. This may apply similarly to the technology in this report, but it may not be. More insight / reliability about this can only be obtained by carrying out a measurement series at a second company location.

The choice in the particulate matter pilots to perform measurements at one company location also means that the reduction percentage of 41% is based on one measurement series of six instead of 12 observations. The reduction found is statistically significantly different from zero. The 95% confidence interval (the upper limit and the lower limit between which the final reduction percentage lies with 95% certainty) is the reduction found to be ± 15 percentage points. However, if a complete dataset of 12 observations were available at two locations, and if the dispersion in that dataset were to remain the same as in the current dataset, the higher number of observations would decrease the 95% confidence interval to ± 11 percentage points.

Other measurement series from the past can also be used to determine a margin of uncertainty. In Winkel (2020) this was done for the reduction percentages for PM_{10} of the techniques already included in the regulations.

b. Case-control over time strategy instead of physical test and control houses

It is often difficult to find two identical practical stables, which is also the case in this pilot. That is why measurements were taken according to a "case-control over time" strategy. A technique is then installed in a test stable where the reduction percentage is determined by means of measurements during on-days versus off-days. Both the case control and the case control over time strategy have their advantages and points for attention. In practice, small (systematic) differences in indoor climate and air quality are often seen in two identical barns, for example because one barn is predominantly sheltered from the other or there are small differences in the climate control. Even in identical stables there are sometimes differences in animal performance (for example in mortality) and the wetness of the litter differs due to the digestion by the animals. Such small differences can be neutralized by constantly switching the treatment between houses. However, with technical systems that must be built in, this is a costly, time-consuming, and impractical process. In a case-control over time strategy, the impurities between houses do not exist. Shortly before or shortly afterwards, the shed where the test treatment is applied is also the shed where the control measurement is carried out. There are two points for attention in this strategy: the on-measurement and the off-measurement must be carried out as close together as possible to avoid too great differences in the ventilation flow rate, and the on and off periods must not influence each other. If these conditions are met, the case control over time strategy is a sufficiently pure basis for comparison. The case-control over time strategy has not yet been included in the latest versions of the Dutch measurement protocols, but the strategy is included in the VERA protocol for "Livestock housing and management systems" (VERA, 2018b). The strategy has also been widely used in recent years in measurements of reduction techniques for particulate matter. Results obtained with this strategy have been accepted in peer-reviewed scientific journals and accepted by the national government for inclusion in the official "List of Emission Factors of Particulate Matter for Livestock Farming". Here the Dutch protocols need an update.

c. Measurement method PM_{10} indirectly equivalent to EN 12341:2014

The applied measurement method for PM_{10} (DustTraks, models 8520 and 8530) has two types of errors: the method underestimates the actual PM_{10} concentration in houses (systematic error or bias) and the method has a relatively large variation between devices (random error). For this reason, the method was not yet included in the measurement protocol for particulate matter (Ogink et al., 2011).

However, the most recent VERA protocol (VERA, 2018a) already sets the requirement that a PM_{10} measurement method must be equivalent to the EN 12341: 2014 reference sampler (CEN, 2014). By using correction factors on the raw data from the DustTrak, this device is indirectly made equivalent to the reference sampler. The relatively large random error of the method has been compensated for by performing the measurements in duplicate, i.e. with two devices. When both DustTraks have measured correctly, the average of both concentrations is taken. If one DustTrak has not measured correctly during a measurement, this data will not be used. This was the case with measurement 6. If both devices did not measure correctly, the entire measurement was not used. In addition, the various devices in the pilot were compared with each other before and after each measurement to detect abnormal devices and to clean and maintain them at an early stage. In this way, the DustTrak models can be used to measure relative differences between case and control days. Here the Dutch protocol from 2011 needs an update. A gravimetric method is preferred for the measurement of PM_{10} emission factors, which must therefore be accurate on an absolute scale. This method is directly equivalent to EN 12341: 2014 and has a smaller random error between devices.

d. Sensitivity and analysis for no local measurement of CO_2-background concentrations

For these measurements, it was decided not to measure concentrations of CO_2 in the immediate vicinity of the house. Instead, CO_2 has been chosen for a fixed value of 400 ppm which could have been up to several tens of ppm higher or lower. To provide insight into the effect of a lower or higher CO_2 background, the reduction percentage was once again calculated based on a very low fixed background of 300 ppm and a very high fixed background of 500 ppm (these background concentrations affect the calculation of the ventilation flow rate). through the CO_2 balance method and subsequently in the emission calculations and the reduction percentage). The reduction percentages thus obtained were 40.6% at 300 ppm, 40.9%

at 400 ppm and 41.3% at 500 ppm. This sensitivity analysis shows that the reduction percentage is hardly influenced by the chosen fixed background for CO_2. This is because a) the concentration difference between inside and outside is large, and b) the small "error" in calculating the ventilation flow is made on both case and control days. In case of lower concentration differences between inside and outside, and when measuring an absolute emission factor, a CO_2 background must always be determined.

e. Sensitivity analysis for no local measurement of PM_{10} background concentrations

For these measurements, it was decided not to measure concentrations of PM_{10} in the immediate vicinity of the house. Instead, the average concentration during the measurement days of the nearest RIVM monitoring station was used for PM_{10}. To provide insight into the effect of a lower or higher PM_{10} background, the reduction percentage has been recalculated based on a reduction or increase in the PM_{10} background concentration by 20 µg / m3 (these background concentrations affect the emission calculations and the reduction percentage). The reduction percentages thus obtained were 41.0% with a reduction of 20 µg / m3, 40.9% with the background concentration of the nearest measuring station and 40.7% with an increase of 20 µg / m3. is affected by the background PM_{10} concentration. This is because a) the concentration difference between inside and outside is large, b) the small "error" in calculating the emission is made on both case and control days, and c) the wind direction on both measurement days is comparable per on-off measurement. has been. At lower concentration differences between inside and outside, and when measuring an absolute emission factor, a PM_{10} background should always be determined.

Several general discussion points are discussed below.

Distribution of measurements over year and production period

Section 3.1 shows that the measurements are not completely evenly distributed over all phases of the calendar year. On the one hand, this is inherent to a measurement series of six successful measurements. On the other hand, the pilot was related to incidents in the sector, vacancy of a company due to the delivery and reconstruction of animals and the loss of measurement technicians due to illness. Because the measurements are not aimed at determining an absolute emission factor but at a reduction percentage, and because the working principle of ionization techniques is unlikely to be influenced by seasonality, the uncertainty caused by this omission is probably small.

Agricultural conditions

The measurements largely meet the agricultural conditions described in appendix 2. One point that is not met is the higher failure rate. In the first production round, this percentage was higher than the norm in the agricultural conditions. This can be explained by the fact that the failure rate in the organic sector is on average higher than in the regular sector (KWIN-V 2019-2020). Other factors may also have played a role, but this has little or no effect on the emission-reducing principle of this technique.

Settling time

During one measurement, the stabilization time of at least one hour was not considered, the data shows no reason to cancel this measurement.

Other measurement reports

No other measurements were performed with this technique in accordance with measurement protocols for the agricultural sector (Ogink et al., 2011). However, measurements were carried out by the supplier in-house. These measurements were not carried out in accordance with the measurement protocol and with non-validated measuring equipment. One measurement was taken at the same location as the location in this report. Reductions of 50 to 63% on the particulate matter concentration in the house have been found over a short period of time (Monteny Milieu Advies, 2019). These reductions are higher than the reduction percentages stated in this report.

Side effects and transfer

$PM_{2.5}$

No measurements were taken into the reduction of $PM_{2.5}$ in this study. Based on the study by Cambra-López et al. (2009), it can be expected that this system will also give a lower reduction for $PM_{2.5}$.

Ozone

Ionization can lead to the production of ozone. In the study by Cambra-López et al. (2009), the ozone concentration has always remained below the minimum detection value. A certain ozone odor could only be detected at very low ventilation rates, such as in young broilers. As soon as the ventilation started to run at a minimum, there were no more indications of the presence of ozone.

Methane/nirous oxide

As far as is known, ionization has no effect on the formation or removal of methane (CH_4) and nitrous oxide (N_2O) from barn air. No measurements were taken of this in this project.

Fire hazard

Research into the fire hazard of another ionization technique indicated that the chance of a dust explosion due to discharges from the ionization system is negligible (de Feijter and Reijman, 2014). There are no reasons for a higher hazard with the ionization system described in this report.

Electromagnetic fields

The high voltage applied in ionization creates an electromagnetic field, which may have health effects on humans and animals. In this report no further research has been done into the occurrence of this in this ionization system. It may be assumed that the supplier will implement the system in such a way that this will not result in any harmful effects.

Translation to other poultry categories

The HD ionization lamps can in any case be used in poultry farming for laying hens, both regular and organic. In addition, the system could be applied to other animal categories within the main category Chickens (E) and Turkeys (F), because the HD ionization lamps do not appear to be subject to the effects of ventilation flow rate, particulate matter concentration in the house or production stage. However, the present measurement report does not clarify this. The litter quality of meat ducks differs from that of other poultry categories in the dry matter content (approx. 30% compared to> 50%). In the second half of the growth period, after the animals have been transferred to another barn, new bedding is applied daily. Application of the system during the first phase of the growth period, before transfers, would thus be possible. Whether the same effect is achieved during the second phase of the growth period will have to be investigated by means of measurements.

5 Conclusion and advice

The HD ionization lamps from Freshlight can reduce the emission of PM10 in laying hen houses. Based on six measurements at one laying hen house, in which the relevant measurement protocols have been followed as much as possible, this reduction is an average of 41%. This reduction is statistically significantly different from zero.

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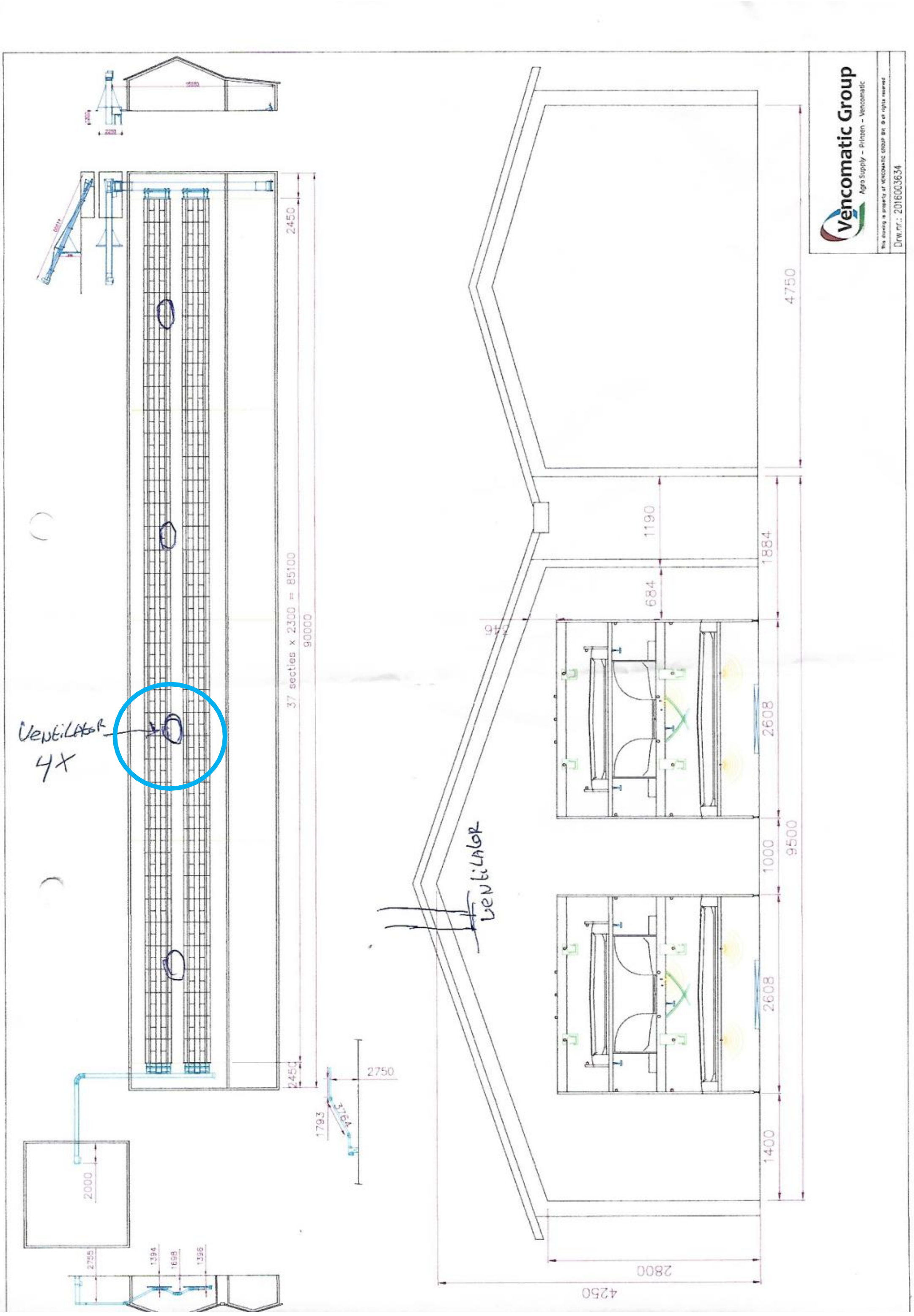
Attachment 1: Discription barn

Characteristic	**Description**
Barn	
Year of construction	1994
RAV code en description	E 2.11.4 aviary housing, 55-60% of the living space grids with a manure belt below with 0.7 m3 per animal per hour of manure aeration. Turn manure belts at least once a week. Timetables at least in two floors (BWL 2005.05.V1). Organic laying hens with outdoor range
Emission factors	Emission PM10: 65 g / animal place per year
Dimensions (l × w × h gutter / hnok)	Ammonia emission: 0.037 kg / animal place per year
Orientation of the barn	Odor emission: 0.34 OUE / animal place per second
Animals	
Number of hens at the start	Approx. 12,000
Occupancy at setup	Approx. 14 chickens per m² of litter floor area
Notice them	Nick Chick (white) later Hyline Brown (brown)
Climate control	
Description air inlet	Via inlet valves in the side walls and via manure belt aeration: 0.7 m3 / hour per hen
Description air outlet	Stable with 4 compartments (not separated airtight). Each compartment has 1 ridge fan with Ø 80 cm, each max. Approx. 13,000 m3 / hour
Ventilation control	Total: approx. 52,000 m3 / hour (approx. 5 m3 / hour per hen)
Target temperature	Based on house temperature and negative pressure Approx. 19–20 ° C
Heating system	No
Business operations	
Description of the husbandry system	Aviary housing in 2 system rows and 3 litter corridors. The system is 37 sections, each 2.30 m long (system length: approx. 85.10 m)
Description feeding system	Feeding chains through the aviary system: two circuits per system row
Feed times	Feeding times: five to six times a day, spread over the light period
Enter	Laying meal 1, 2 and 3
Description drinking water system	Water lines with drinking nipples and drip trays: three lines per system row
Drinking times	During light times
Litter management	The stable is sprinkled with a small amount of straw. Litter is also occasionally applied
Description of lighting	Skylights above the litter aisles with full spectrum LED lights
Light regime	16L: 8D, lights on from 4:00 AM to 8:00 PM (wintertime)
Cleaning regime	After the chickens have been cleared, the litter manure is removed, and the barn is wet cleaned
Production cycle	
Age at design	Approx. 17 weeks
Age at culling	Approx. 80 weeks
Vacancy between couples	Approx. 2 weeks

Air photo of the company. The poultry barn where the measurements were taken is the top barn.

Air photo of the company area. The poultry barn where the measurements were taken circled in blue.



Plan and section of the shed. Measurements were carried out at the blue-circled ventilation duct.

Front side barn

Back side barn

Side view of barn with covered outdoor area (not in use during measurements)

HD-ionization lamps on two places in the barn.

Attachment 2 agricultural conditions

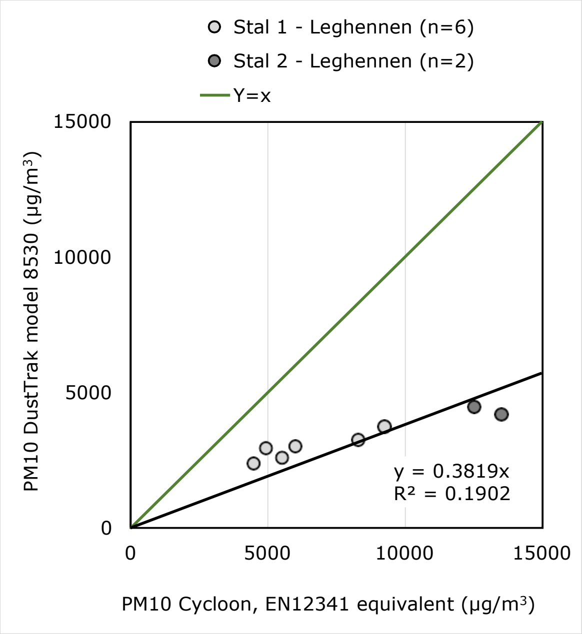
Part	Agricultural condition:	Suffice
Housing	During the measurement period, the applicable animal welfare standards are met. Before the measurement period, the house must have been used for housing laying hens for at least two months.	Yes Yes
climate	The laying hens are kept under such conditions that the CO2 concentration in the air of the section remains below 3,000 ppm.	Yes
Nutrition	The chickens receive a standard feeding schedule (CVB) with a minimum of 14 g RE / convertible energy laying hens (OElh in MJ / kg) in the feed. The feed consumption per laying hen present from 20 weeks must be at least 105 g per animal per day. Water supply is unlimited. Declaration of no use of feed additives that may have a main or side effect on the pH of the urine and / or the urea excretion via the urine.	Yes, these levels have no effect on particulate matter emissions Yes, these levels have no effect on particulate matter emissions
production	Egg production must be at least 300 eggs / chicken on an annual basis.	Yes
Health and hygiene	The laying hens receive standard veterinary care. The failure rate may not exceed 10% in the entire production period.	No, measurements were carried out in a barn with organic laying hens with a higher dropout percentage, see KWIN-V
Number of animals	The group size is at least 750	Yes
Registration	For four weeks prior to the measurement: - total number of kg of feed supplied in the section / shed - total number of kg of litter provided in the section / shed - total amount of water consumption in the measuring section / shed - present + incoming and outgoing animals (also during the measurement) During the measurement: - production: number of eggs, egg weight and mortality - feed intake - times of removal of (slurry) manure from the section / shed - registration of feed composition - CO2 concentration - the way in which animal welfare standards applicable during the measurement period are met	No, these indicators have hardly any effect on the reduction of particulate matter Yes

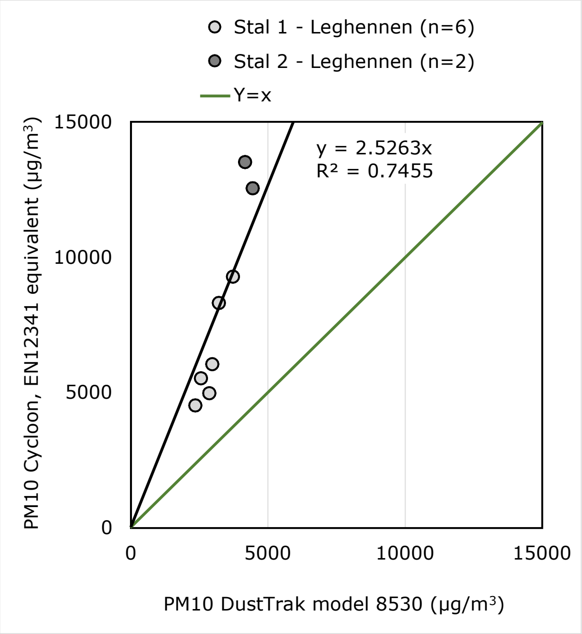
Attachment 3 Determination of correction factor for DustTrak model 8530

The relationship between the PM_{10} concentration determined with the DustTrak and the gravimetric method for PM_{10} as used at Wageningen Livestock Research was determined by carrying out simultaneous measurements (n = 8) in two different laying hen houses with both methods side by side. Of the two methods, the gravimetric method is equivalent to the PM_{10} reference sampler in EN 12341: 2014 (CEN, 2014).

The figures below show the relationships between the two measurement methods. In the left figure, the equivalent method is placed on the x-axis and the DustTrak model 8530 on the Y-axis. The left figure shows that the point cloud and the associated regression line lie below the green Y = x line. This means that the DustTrak underestimates the actual concentration.

In the right figure, the DustTrak model 8530 has been placed on the x-axis and the equivalent method on the Y-axis. In the corresponding regression function Y = 2.5263x now x is the DustTrak concentration. If one wants to convert the DustTrak concentration x to the actual concentration Y, then that concentration x must be multiplied by the factor 2.5263 or rounded to **2.53**.





Attachment 4 Calibration measuring equipment

Particulate matter analysis PM_{10}

DustTrak Aerosol Monitor Model 8520 and DustTrak II Aerosol Monitor Model 8530.

All instruments used have a recent certificate from the supplier. After every stable measurement of more than 2 x 24 hours, the instruments are cleaned well on the outside and inside and, if necessary, provided with a new filter. The latter is indicated by the instrument itself.

Subsequently, the instruments in the air laboratory ran in the so-called survey mode for a few days. The instrument is rinsed with the relatively clean ambient air. A "zero filter" was used to check whether the zero-value needed to be adjusted. For Model 8520, the new zero value was entered for each measurement. With model 8530, zeroing the device is more difficult and the choice was made to note the current zero values and to correct for the higher zero value later during the data processing. After approximately 3 days of rinsing, the instruments are switched off and ready for the following measurements. The instruments are annually returned to the supplier for maintenance and adjustment, linked to a new certificate. If, based on the raw data obtained, it appears that the instruments are not reliable, they are excluded from the dataset for further processing. A measuring technician then assesses whether the instrument should be sent for adjustment. If unreliable data is repeated during a subsequent measurement, the instrument will certainly be sent to you.

CO2-analysis

Testo type 435 with IAQ probe for CO_2 and Vaisala CO_2 sensor with Carbon Dioxide Probe GMP252.

The instruments have recent certificates from the supplier. Before the instruments were used in the research, they were calibrated in our own air laboratory. The calibration curve of each instrument has been established by offering a dilution series of CO_2 calibration gas.

The Testo became unstable at one point and was then replaced by the Vaisala sensors after a joint bridging period. The Vaisala sensors do not have their own storage memory and are therefore used in combination with Koenders data loggers.

Temperature and relative humidity

Escort RH iLogger EI-HS-D-32-L.

The logger is set to a measurement frequency of 2 minutes. The instrument is thoroughly cleaned after each measurement. Then it comes to lie in a holder together with a few other sensors. This makes it possible to determine a possible deviation. These loggers have not been recently calibrated. They are therefore only used to indicate the measurement conditions.

Temperature range: -40ºC to + 70ºC
Humidity range: 0-100% RH
Accuracy:
± 0.35ºC (from -40ºC to 0ºC)
± 0.25ºC (from 0ºC to + 70ºC)
Humidity ± 3%

Attachment 5 Concept BWL-description

Pay attention! This is a draft at the time of publication of this report.

System number	**BWL 2019.XX**
System name	**Ionization by means of carbon brushes; nn% reduction of particulate matter (PM_{10})**
Animal category	**Additional techniques for emission reduction of particulate matter from poultry**
System description of	**XXX 2019**
Working principle	The emission of fine dust (PM_{10}) is limited by adding a charge to the dust particles in the house. For this An ionization system with carbon brushes is installed in the barn that spreads ions. Due to the charge, the dust particles bind to water molecules in the air and the particles become heavier, these heavier particles deposit on the ground.

THE TECHNICAL IMPLEMENTATION OF THE SYSTEM; ARCHITECTURAL		
	Part	**Execution requirement**
1	Requirements according to description with which system is combined.	

THE TECHNICAL IMPLEMENTATION OF THE SYSTEM; TECHNICAL EQUIPMENT		
	Part	**Execution requirement**
2	Housing form	Depending on animal category and housing system
3a	Ionization system	The carbon brushes are attached to the housing of a lighting system[5].
3b		At least 1 carbon brush per 1.5 m² shed surface.
3c		A minimum of 25 $*10^6$ ions/s are produced per carbon brush.
3d		Placement of the lighting units in accordance with the placement plan of the supplier.
4	Recording equipment	The following recording equipment must be present: - equipment for registering the use of the ionization system (e.g. hour meter, (k) Wh meter)

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[5] An earlier embodiment of the ionization lamp has been patented under number 1042530.

USING THE SYSTEM		
	Part	**Usage requirement**
a	Living surface	Number of animals / m² living area according to description with which system is combined.
b	Ionization	Ionization from 0 days after setup[6]
c	Maintenance contract	Concluding a maintenance contract with the supplier or another expert party is strongly recommended[7]. The maintenance contract should include an annual inspection and maintenance of the ionization system. The tasks of the supplier / expert party are also included in this contract.
d	Registration	For the purpose of checking the operation of the system, the following data must be automatically recorded: - the output voltage; - the output amperage. During the check, a printout of the current and previous production period must be available for the recorded values.
Operation result		Emission reduction of particulate matter (PM_{10}) of nn% compared to the emission factor of the housing system with which it is combined.
Reference measurement report		Pilots to reduce particulate matter emissions from poultry houses: HD ionization lamps from Freshlight

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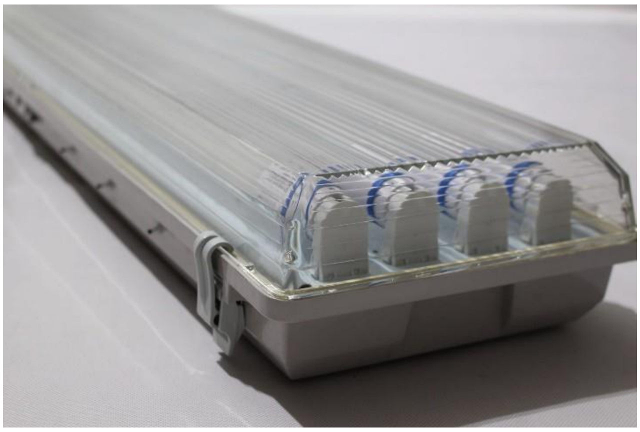
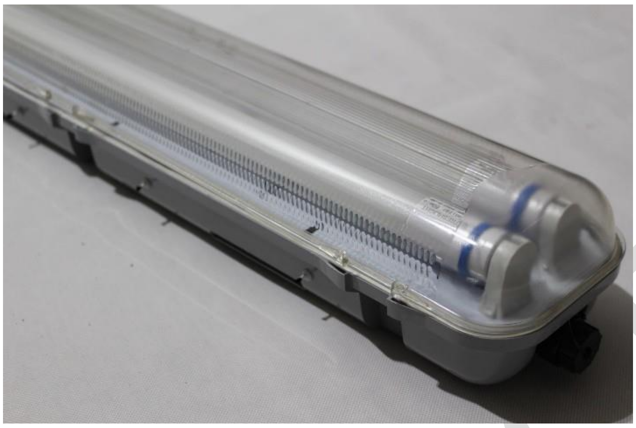
[6] In the systems where eggs are hatched in the house and then the chicks are reared in the same house to a certain age (categories E 5.9.1.1 and E 5.9.1.2), switch on the ionization when transferring to the follow-up housing.

[7] A maintenance contract is a good way to prevent the user from having problems with the accountability for enforcement.

Principle illustrations of HD ionization lamps with carbon brushes





Name: Ionization by means of carbon brushes; nn% reduction particulate matter (PM_{10})	**Number:** BWL 2019.XX
	System description: XXX 2019

To explore
the potential
of nature to
improve the
quality of life

Wageningen Livestock Research
Mailbox 338
6700 AH Wageningen
T 0317 48 39 53
E info.livestockresearch@wur.nl
www.wur.nl/livestock-research

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