VERA TEST PROTOCOL

for
Air Cleaning Technologies

Version 2:2018-09

VERA

Verification of Environmental Technologies for Agricultural Production

Foreword

To meet the environmental challenges in livestock production, new technologies are being developed within EU member states and elsewhere. These so-called environmental technologies are designed to potentially enhance the eco-efficiency of livestock production by reducing material inputs, emissions of pollutants, and energy consumption, recovering valuable by-products, and minimising waste disposal problems. Environmental technologies in agriculture can be introduced in different stages of the production chain, e.g. techniques applied in animal houses or techniques for manure storage, processing, or land application.

However, central stakeholders, such as farmers and authorities, only have limited information about the performance of these technologies, which hampers their diffusion in the agricultural sector. The Danish Ministry of Environment, the Dutch Ministry of Infrastructure and Environment, the German Federal Ministry of Food and Agriculture, and the German Federal Environment Agency, in cooperation with international technical experts, have therefore started the development of common test protocols for testing and verification of these environmental technologies for agricultural production. The VERA test protocols are designed to investigate the environmental performance and operational stability of a technology and thus provide reliable and comparable information about the performance of technologies to farmers, authorities, and other stakeholders.

This initiative is organised within VERA – 'Verification of Environmental Technologies for Agricultural Production'. The VERA cooperation was established in 2008 to promote an international market for environmental technologies for agricultural production. The overall purpose of VERA is to fill the information gap of central stakeholders by offering independent verification of the environmental performance and operational stability of environmental technologies determined by applying specific VERA test protocols.

The first version of the protocol for air cleaning technologies was finalised in 2010. The present Version 2 was published in September 2018.

Questions and comments on the VERA test protocols should be sent to

International VERA Secretariat
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Amendments

This edition of the VERA test protocol has been thoroughly revised to reflect the latest state-of-the-art and differs from the earlier version 1:2010 as follows:

a. The order of sections has been modified to be uniform for all VERA test protocols and to be consistent with the basic VERA structure for test reports. The general format and structure of the documents have been harmonised by a new **'high level structure'**, which should help the user navigate through the documents and is closer to the format of an international standard.

b. The requirements and recommendations are more precisely indicated, especially for the description of sampling and testing certain parameters.

c. There is a more detailed description of data treatment and calculation of different parameters, e.g. emissions and N balances.

Previous editions

VERA Test Protocol for Air Cleaning Technologies Version 1:2010-09

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1. Introduction

The objective of this test protocol is to specify the test procedures for the environmental efficiency of air cleaning technologies for agriculture.

This includes definitions, specific requirements and conditions for testing, measurement and sampling methods, processing and interpretation of measurement results, and reporting specifications. More general requirements for the parties involved in the test and the individual process steps for testing and verification are laid down in the 'General VERA Guidelines', which were approved by the International VERA Board.

This document was drawn up by nominated international experts of the 'International VERA Expert Commission (IVC)' for air cleaning technologies.

During the last 20 years, air cleaning systems have been developed for application in livestock production in north European regions with high animal densities. Initially, air cleaning was especially applied in incidental cases as a means of abating the odour nuisance of livestock operations that increased their production scale near residential areas. In this protocol, an air cleaning system is defined as a unit connected to the ventilation system of a livestock housing unit, in which the outlet air is treated to reduce the emission of one or more pollutants.

Technological developments were mainly based on adapting biofiltration techniques with organic package materials. In a later phase, new policies and regulations to control the ammonia deposition for the protection of sensitive ecosystems stimulated the development of air cleaning systems designed for ammonia removal. A variety of chemical and biological air cleaning systems have been developed for this purpose.

More recently, multi-pollutant air cleaners for the combined removal of ammonia, odour, and small particles defined as PM10 and PM2.5 were introduced. These scrubbers combine physical, chemical, and biological removal principles. Removal of 'fine dust' has become an issue in regions with high background concentration of PM10/2.5 in ambient air. EU limit values set in 2008 for both PM10 and PM2.5 concentrations in ambient air to protect public health can be exceeded by industrial and agricultural activities. The capacity to remove PM10 and PM2.5 has made air cleaning systems more interesting for application in poultry facilities that exceed 'fine dust' threshold levels in the environment.

Currently, about ten European manufacturers are supplying air cleaning systems to livestock producers in Northern Europe. Up until now, they have had to deal with various admission and assessment procedures in the different nations. Overcoming this fragmentation by an international test protocol and verification scheme will benefit all stakeholders in assessment procedures, saving time and costs in implementing eco-efficient technologies.

The aim of the VERA verification statements is for its information to be optimally used by different stakeholders in the member states. This means that the test protocol should provide a broad array of reliable information that can be analysed and summarised during the verification so that it can be directly or indirectly used as widely as possible by different national users.

However, for reasons of cost and time, test protocols have restrictions with regard to the number of parameters to be evaluated and the applied methods. The starting point in the design of the present test protocol, therefore, was to create an optimal balance between reliable information that meets the demands of different users and costs in terms of time and budgets to carry out the test procedure. Nevertheless, it is recommended that durability and the maintenance cost of the air cleaners are evaluated three to five years after market introduction, although the present test protocol does not include specifications for such an evaluation.

2. Scope

This protocol specifies the information needed for testing and verifying the environmental performance and operational stability of air cleaning technologies for livestock housing systems.

2.1. Definition of 'air cleaning systems'

In this protocol, technologies for air cleaning are defined as:

- End-of-pipe installation for cleaning the exhaust air of forced-ventilated animal housing systems from specified contaminants such as odour, ammonia, and dust.
- Also called: air purifying/air treatment systems or air scrubbers.
- Air cleaners operate on different removal principles (physical, biological, and/or chemical). Currently, biofilters, biotrickling filters, acid scrubbers, and multi-stage air cleaning systems are applied for the removal of pollutants from the exhaust air of animal housings. They differ in applicability and removal performance.

The most frequent air cleaning types are defined in Section 5.

2.2. Targeted results and information

The information specified includes:

- A comprehensive system description: working principles, system description, essential operation parameters, applicable animal housing systems, and user manual.
- Technical performance of the air cleaner based on data collected during the test period.
- Measurement methods including requirements, sampling strategy, data collection and handling, calculation methods, and reporting.
- Evaluation parameters to assess the environmental performance of the system tested.
- Evaluation of operating stability of the air cleaning system.

The test period and the number of sampling days are determined by the requirements for a statistically adequate evaluation of the environmental performance of the system. During the test period, the operational stability and deviations from normal operational functioning must be observed, recorded, and reported in the test report. However, specific test parameters for the assessment of long-term operational reliability and durability are not included in this protocol.

2.3. Use of results for verification

After a test has been completed, verification of the environmental efficiency based on the test results can be carried out in accordance with this protocol and the General VERA Guidelines.

VERA does not endorse, certify, or approve technologies!

VERA verifications are based on an evaluation of the performance of the technology under specific, predetermined criteria and the appropriate quality assurance procedures. VERA makes no expressed or implied warranties as to the performance of the technology and does not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Further, the end user must be aware that the countries involved in VERA have different legal requirements, which will influence the status and use of this verification statement in each country.

3. Normative references

The referenced standards in the following text and in the bibliography are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

4. List of abbreviations

a	Annus, Latin for year
A	Animal
AP	Animal place
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
DM	Dry matter
FTIR	Fourier transform infrared spectroscopy
GHG	Greenhouse gases
IVB	International VERA Board
IVC	International VERA Committee
K	Potassium
LU	Livestock unit
N	Nitrogen
NH_3	Ammonia
N_2O	Nitrous oxide
NO_x	refers to NO (nitric oxide) and NO_2 (nitrogen dioxide)
OU_E	European odour units
P	Phosphorus
PM	Particulate matter
ppmv	Parts per million by volume
TAN	Total ammoniacal nitrogen
VERA	Verification of Environmental Technologies for Agricultural Production

5. Terms and definitions

Air cleaner
End-of-pipe installation for cleaning the exhaust air of forced-ventilated animal housing systems from specified contaminants such as odour, ammonia, and dust.

Acid scrubber
Belongs to the category of chemical air cleaners. A trickling filter in which the pH of the washing liquid is kept at low levels (pH < 5) by the addition of acid (usually sulphuric acid) in order to remove ammonia from the contaminated air. The ammonium ions produced by the chemical reaction between NH_3 and the acid are removed from the system with the discharge water. Due to the low pH-value, microbial degradation does not take place. Thus, odour reduction is relatively insignificant and subject to considerable fluctuations.

Air flow
The volume flow of exhaust air in $m^3 h^{-1}$ can be given for the entire animal house or per animal (place).

If the system is based on **partial air cleaning**, the total airflow is split into two airflows: an airflow going through the air cleaner and an untreated airflow blown directly out into the surroundings.

When the external dimensions of a filter are evaluated, or when the air filter is subsequently up/downscaled on another farm, the air flow per area of front filter in $m^3 h^{-1} m^{-2}$ is a basic parameter.

The air flow can also be given per filter volume in $m^3 h^{-1} m^{-3}$, which is the reciprocal value of the retention time.

Air purifier
See 'air cleaner'.

Ammonia (NH_3)
A gas derived from urea or uric acid excreted by livestock and implicated in acidification and nitrogen enrichment of sensitive ecosystems.

Animal housing system
A housing system is defined by the way a certain animal category is stocked (the floor and pen design), the system for the management and internal storing of manures produced, the ventilation system to control indoor climate, and the method and regime used to feed and water the animals.

Animal category
Different types of animals according to their species (e.g. pigs, cattle, chicken, ducks, and turkeys), sex, age, and scope of production (e.g. breeding, rearing, growing and finishing for meat, milk, or egg production).

Biofilter
An installation in which the exhaust air is led through a filter bed, usually consisting of organic material such as root wood or wood chips. The filter material has to be kept moist so that gaseous contaminants are absorbed by the moisture film of the biofilter material and generally oxidised or degraded by microorganisms living on the filter material. In order to compensate for evaporation losses and to guarantee proper functioning, the exhaust air either has to be pre-humidified, e.g. by a washer, and/or the filter has to be moistened by controlled intermittent irrigation.

Biofilters are mainly used to eliminate odours in housings with no bedding material. They can also be used for dust separation if coarsely structured filter material, which does not tend to clog, is used at least on the crude gas side. Biofilters, as a sole process stage, are not suitable for ammonia separation.

Biotrickling filter
A trickling filter for the removal of dust, ammonia, and odour by means of absorption of the contaminants in the liquid phase and degradation by microorganisms settling on the filter elements as a bio film. Ammonia is degraded by a bacterial conversion to nitrite and nitrate, a process called nitrification. The accumulated nitrate, and especially nitrite that may be toxic to the microorganisms, has to be removed with the discharged water.

Chemical scrubber
A trickling filter that removes pollutants by means of absorption of the contaminants in a liquid phase with specific chemical properties. In the case of using pH for the facilitation of pollution removal, the pH value could be obtained by addition of an acid, e.g. sulphuric acid (see 'acid scrubber') or by the addition of a base.

Denitrification unit
Biological denitrification units are used for removing oxidised nitrogen species originating from NH_3 in the polluted air. Denitrification is a biological process in which bacteria use one or more of the oxidised nitrogen species, i.e. nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO), and nitrous oxide (N_2O), for respiration under anoxic conditions while degrading organic material. The ultimate end product of denitrification is atmospheric nitrogen, N_2, which is harmless in the environment, and N_2O, which must be minimised through the controlled denitrification process.

Prior to denitrification, NH_3 has to be oxidised within the air cleaner or in a separate unit external to the air cleaner. The growing of nitrifiers strictly depends on temperature. Therefore, it is recommendable to avoid energy losses as far as possible. Good operation results will be achieved at temperatures above 15°C, otherwise nitrifying bacteria growth and nitrification rates are very low.

Downtime
The period of time when the system tested is not operating as a result of malfunctions.

Dust
See 'particulate matter'.

Filter area
The front area of the filter where the air flows in is based on the external dimensions of the filter (m^2).
The specific filter area is the area of the filter material per volume of filter element (m^2 filter, m^3 filter element).

Multi-stage cleaning system
Multi-stage exhaust air cleaning systems, usually consisting of two or three stages, combine different cleaning principles and their advantages (see Table 1), e.g. an improved ammonia separation by an acid scrubber with an optimal odour degradation in a biofilter.

Odour
A pleasant or unpleasant smell caused by different odorants with very different chemical, physical, and biological properties.
The odour concentration is given in European Odour Units per cubic meter air ($OU_E\ m^{-3}$), and the concentration is measured by olfactometry in accordance with the European CEN-standard (EN 13725).

Particulate matter (PM)
Often also called dust.
Fine solid or liquid particles suspended in a gaseous medium.
Different fractions are specified by the aerodynamic diameter as well as by the sampling and evaluation method as defined in the respective standards, e.g.

Term	Definition	Standard
PM10	Particulate matter that passes through a size-selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter.	EN 12341
PM2.5	Particulate matter that passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter.	EN 14907
Inhalable dust (ID)	The total airborne, finely divided solid and liquid particles that are inhaled through the nose and mouth, generally with an aerodynamic diameter of more or less equal to PM100.	ISO 7708 EN 481
Total dust (TD)	Airborne particles that can be collected using 37-mm filter cassettes.	NIOSH 0500
Total suspended particles (TSP)	Archaic term used by US-EPA before PM10 was introduced: 'particles up to 25-50 µm, depending on wind speed and direction'. Relates roughly to a PM35.	40 CFT 50, appendix B

Physical air cleaners
Experimental installations where odorants are intended to be oxidised with the aid of UV-radiation, ozone, or a plasma reaction technology. Since the effectiveness of these techniques and others, which are currently being developed, has not yet been proven in practice to reduce the emission of dust ammonia and odour at a reasonable cost, they are not described in detail here.

Point extraction
See 'air flow'.

Pressure drop
Pressure drop [Pa] across the air cleaner or across the entire system (animal housing and air cleaner) could be presented as a curve or table for different airflow rates ($m^3\ h^{-1}$).

The ventilation fans must be sufficiently pressure stable so as to be able to overcome the flow resistance of the animal housing and the exhaust air cleaning system at all times in order to supply the animals with the required air rates, in particular under summer conditions.

Retention time
The retention time[s] is the period or time length wherein the air penetrates the filter of the air cleaner.

Set of samples
One set of samples includes one sample of the outlet air ('clean gas') and one sample of the inlet air ('raw gas'), taken simultaneously.

Trickling filter
Also called trickle bed reactor or, more commonly, air scrubber or air washer.

An installation in which the polluted air is passed either horizontally (cross-current) or upwards (counter-current) over filter elements that are continuously or intermittently sprinkled with a washing liquid. Due to an intensive contact between the air and washing liquid, the components contained in the contaminated air change from the gas to the liquid phase.

Currently, water and diluted acids are used as washing media. The decisive factor for the proper operation of these installations is that the separated substances contained in the exhaust air, as well as the reaction products, are removed from the system by de-sludging, i.e. the draining of polluted wastewater. Therefore, a fraction of the washing liquid is usually continuously recirculated; another fraction is discharged and replaced by fresh water and/or diluted acid.

The reactor (filter) elements are usually made up of an inert or inorganic packing material that has a large porosity, or void volume, and a large specific area in order to improve mass transfer. For the prevention of aerosol emission to the environment, drip separators are needed in any case.

Three types of trickling filters are common: acid scrubbers, biotrickling filters, and water scrubbers (see the relevant definitions).

Uptime of the system
The period of time when the system tested is functioning.

Water scrubber
Trickling filter that uses water as an absorbent.

6. System description

The manufacturer/applicant is responsible for providing a precise and full description of the system or technology before initiation of a VERA test. This information should be provided as data required for the test body, system users, verification authorities, etc. To some extent, it also forms part of the final test report. The system description must include all relevant and essential information that is needed to:

- organise and design the test;
- enable the farmer to operate, maintain, and monitor the system properly;
- on-line monitor the system, including the key parameters needed for the determination of uptime/downtime of the system;
- allow the verification authorities to check the system after a test has been carried out; and
- provide insights into working mechanisms of the system.

In particular, the **detailed description of the air cleaning system** shall include:

- the range of application with respect to animal category and housing system;
- the system's function in detail and the expected performance of the system with respect to the pollutants (i.e. odour, ammonia, and dust) to be treated;
- illustrations and/or diagrams of the system (top and sectional views, details if necessary);
- the dimensioning of the system (e.g. volume of packing, surface area, and air loading rate per m^2);
- a list of the (technical) components, including type (e.g. material and characteristics), technical and functional description, and arrangement;
- a list of the essential design and operational parameters (ranges) that are specific for the air cleaning system to be tested and are decisive for proper functioning (see Annex A). Particular focus shall be given to these parameters and their ranges, as they are needed for up- and downscaling of a system and for the evaluation of how the system can be changed before a new test is needed;
- a list of key parameters to be electronically or manually logged during operation of the system as part of system surveillance; this list should include those parameters listed in Annex B and a description of how they are controlled;
- a compilation of the input materials needed and the liquids and wastes produced (including amount and relevant chemical composition);
- detailed instructions for operation, service and maintenance, and surveillance; and
- which parameters are necessary for the calculation of the uptime/downtime of the system (the test body is, however, responsible for a professional evaluation of whether this information is reliable and sufficient).

The manufacturer/applicant must provide general information about:

- detailed instructions on operation, service, maintenance, and monitoring;
- potential risks for animal welfare, occupational health and safety, and the external environment;
- predicted durability of the system and its components;
- warranty provisions; and
- a list of reference units (animal category, type of housing system, animal weights, ventilation rates, and flow resistance in particular), if available.

User manual

A user manual for the technology must be available in the local language. It must be written in consideration of EN 82079: Preparation of instructions - Structuring, content and presentation, which provides general principles and detailed requirements for the design and formulation of all types of instructions, and Machinery Directive 2006/42/EC, which provides the regulatory basis for the harmonisation of essential health and safety requirements for machinery.

The user manual must include the information provided with the system description according to the descriptions above in this chapter and should, in particular, include instructions for:

- the operation of the system and the technical installations;
- the prevention and handling of incidents (environmental safety);
- operational health and safety measures;
- service and maintenance; and
- monitoring of the installations.

Find an example in Annex F.

7. Requirements

This chapter specifies the requirements related to the testing of air cleaning technologies.

In addition, the chapter describes the measurement parameters to be included in the test and a specification of the methods to be used. Finally, the chapter includes requirements to ensure representative feeding and management conditions on the test facility as well as requirements related to the impact of the technology on occupational health and safety and animal welfare.

All more general requirements for the testing and verification procedures, including the qualification of test partners, are specified in the General VERA Guidelines (GVG).

7.1 Pre-testing or preparations for a full test of a technology

The test protocol can be used during the phases of developing a new technology (pre-testing) as well as for the testing of a final technology (ready for sale) with the aim of verification.

It is strongly recommended to carry out pre-testing of a new technology before a final test is initiated and to start a full test of a new technology only when it has shown to be stable and well-functioning. During the pre-testing of a technology, parts of the test protocol can be used in order to clarify and optimise the performance and stability of a new technology. During such pre-testing of a technology, a manufacturer can visit the test facility whenever desired.

However, during the full test of a technology with the aim of a VERA verification, all the requirements stated below have to be fulfilled, including any general requirements outlined in the General VERA Guidelines (GVG), requirements/restrictions on farm visits, and modifications of the technology.

The test of a technology involves various actors:

1. The applicant wishing to have a technology tested.
2. The test institute that carries out the required tests of the technology.
3. The farmer(s) who own the facilities where the tests are conducted.

A detailed **test plan** is to be elaborated by the test insitute according to the template in Annex G, including all relevant parameters.

The applicant/manufacturer is responsible for providing a full description of the system or the technology to be tested prior to the start of a VERA test, cf. Section 6. The description must include detailed instructions for operation, service, maintenance, and surveillance.

7.2 Responsibilities during the test period

During operation of the system, the applicant/manufacturer of the air cleaner is responsible for electronic data logging of a number of key parameters in order to ensure the operation of the system (see Annex B). This logging shall include those parameters essential for the calculation of the uptime/downtime of the system, cf. Section 6.

The test institute shall verify that the selected parameters for surveillance of the operation of the system are relevant, essential, and adequate.

During the test period, the applicant/manufacturer of the air cleaner is not allowed to visit the farm unless they are contacted by the test institute or the farm owner due to problems with the air cleaner. In this case, the applicant/manufacturer can visit the farm, but only in company with the farmer and the test institute.

Any operational problem identified shall be dated and described in the test logbook by the farmer or the test institute. In addition, it shall be noted when and how the problem is solved and signed by the farmer, the applicant/manufacturer, and the test institute when repairs have been finalised.

During the test period, no changes of the technology are allowed that may have a crucial impact on the cleaning process.

If the applicant/manufacturer has conducted tests on earlier models of the air cleaner, all the test reports must be enclosed, including a description of the differences between the models.

The test institute is responsible for coordinating and implementing the test plan and for drawing up all the necessary data record tables. Furthermore, the test institute is responsible for the calculation of the uptime/downtime of the system tested.

Furthermore, the test institute must insure that the logbook is kept in an accessible place in the housing unit, close to the air cleaner.

The farmer is responsible for recording the production conditions in accordance with the test plan. The farmer must also record the time spent on operational problems and maintenance of the air cleaning system.

7.3 Requirements for the test facility

This chapter describes the overall requirements for the layout of farms that are used as test facilities. The requirements for management conditions are described in Annex D.

The air cleaning system shall be tested under farm conditions that are representative of the standard practices of the animal categories for which the system is intended for use. This implies that requirements are defined to ensure both the layout of the test facility and the management conditions during the test period are representative of the applied categories.

In addition, the test facilities used for the test must represent farm characteristics that can be considered representative of standard practices in the country in question. The following items have to be considered:

1. Size of the livestock units involved in the test
2. Stock density
3. Pen design
4. Feeding system
5. Applicability to other housing systems and animal categories
6. Manure removal system
7. Ventilation system: layout and dimensioning in relation to animal numbers
8. Management strategy

The farmer must be able to document the actual crude protein level in the feed during the test period. If the farmer is not able to deliver this documentation, three feed samples must be taken, spread out over the measurement period, and analysed.

7.4 Test design and sampling strategy

7.4.1. Test design

The VERA test is performed on two farm sites.

The test facilities of both installations shall be representative of farms in the participating countries, including unit size, feeding regimes, and ventilation rates, c.f. Section 7.3.

If possible, it is recommended to perform the two tests on farms located in two different countries. In order not to waste money, if there are fundamental operational problems, the tests may be performed on the two farm sites consecutively.

7.4.2. Sampling strategy

The specific sampling and measurement parameters are specified below, with the aim of gaining information on the technical performance of the air cleaner. The test design shall include a monitoring of the system and a continuous logging of key parameters over a period of one year (around the test period). This will form the basis for an evaluation of the operational stability of the system, cf. Annexes A and B.

- The operational stability shall, at a minimum, be verified by monitoring once a year and by at least one visit to each location outside the eight-week measurement periods, with an overall check-up of the 'logbook' and discharge water.
- Weekly checks of the electronic monitoring of secondary parameters (same requirements as during measurement periods).

Table 1: Sampling strategy during an air cleaning system test

Sampling/ Parameters	Requirement	
	Test location A	**Test location B**
Sampling period	≥ 8 consecutive weeks, summer conditions. ≥ 8 consecutive weeks, winter conditions. For tests in broilers: 2 batches, with measurements for 4 weeks at the end of each batch. Aim is to test minimum and maximum conditions.	Identical to location A.
	Summer conditions: Ventilation rate for the animal house must be > 80% of the maximum dimensioned ventilation rate per animal for <u>at least</u> 3 hours per day for 50% of all the measurement days within the 8-week testing period. During collection of samples for odour measurements, the ventilation rate has to be above 80%. **Winter conditions:** Ventilation rate for the animal house shall be low and below 30% of maximum ventilation rate per animal for <u>at least</u> 3 hours per day for 50% of all the measurement days within the 8-week testing period. During collection of samples for odour measurements, the ventilation rate has to be below 30%. For partial air cleaning and for poultry production, individual sampling conditions for that specific case have to be defined in the test plan. However, both summer and winter measurements have to be carried out. A minimum of a two-month interval between the summer and winter measurements is required.	
Sampling points	Simultaneous sampling of inlet and outlet air.	Identical to location A.
Minimum sampling days		
Odour	• 2x8 measurement days. • Odour characterisation (optional).[1]	4 days during winter and 6 days during summer period.
Particulate Matter ('dust')	• Total dust and PM10: 2 days in each 8-week period. • PM2.5 optional.	No dust measurements.
Ammonia	• 2x8 measurement days of 24-hour continuous measurements. • Two-week continuous NH_3 sampling within each of the two 8-week periods for establishing an N-balance.	4 days during winter and 6 days during summer period. Equally spread out over the eight-week period.
Nitrogen balance	<u>For operational stability:</u> • Water analyses once a week (in each period). <u>For N balance:</u> • > 2 weeks (for biofilters: > 4 weeks) within each of the 8-week periods with online gas (NH_3, NO_X, N_2O) and volumetric flow measurements as well as water analyses.	No measurements.
Operation parameters	During measurements of odour and ammonia: • Air volume flow (continuously). • Temperature and relative humidity (before and after the air cleaner) at least once a week. • pH of discharged water.	Identical to location A.
Discharged liquid from the air cleaner	During the 2-week continuous NH_3 measurements, the drained discharge water shall be stored in a tank. Liquid samples from the first day, a day in the middle, and the last day of the two-week period shall be taken from the air cleaner and the storage.	Samples of the recirculation liquid of the air cleaner shall be taken on all days with odour and ammonia measurements.

1 For German authorities: odour characterisation is obligatory.

7.5 Measurement strategy

7.5.1 Calibration, verification, and validation

The calibration of measurement instruments is essential and part of the definition of the configuration. This relates to calibration procedures that are only performed perennially or annually, as well as for those that need to be done before each use. The calibration must also take into account possible cross-interference from other gases in the test house as well as temperature, relative humidity, etc.

Any calibration and verification procedures and estimates of the measurement uncertainty for the relevant parameters must fulfil the requirements of ISO 17025 and be documented and reported.

For all parameters, the measuring range and detection limit of the respective measurement method must be adequate and must be documented in the test report.

Specific requirements for ammonia measurements:

The following are the minimum required QA parameters that must be documented by the test institute and made available upon request:

Table 2: Quality assurance requirements for NH_3 measurements

QA parameter	Requirements
Detection limit	The minimum detectable concentration of ammonia. Defined as the concentration at which the probability of a false positive is 1% and the probability of a false negative is 50%. Typically, this is determined as 3 times the standard deviation of at least 7 blank measurements, but other procedures exist.
Limit of quantification (LOQ)	The minimum concentration at which a concentration can be reported with acceptable precision, which is typically determined as 10 times the standard deviation of at least 7 blank measurements, but other procedures exist. Any results below the LOQ cannot be included in the calculation of removal efficiency but may be set equal to the LOQ. It is recommended that the LOQ for ammonia removal in air cleaners is at least <1 ppm and preferably <0.5 ppm.
Measurement uncertainty	The propagated uncertainty of the overall method including calibration function uncertainties and other uncertainties involved (e.g. dilutions). For ammonia, the measurement uncertainty shall not exceed 15%.
Measurement range	The concentration range at which the calibration function (see below) and method uncertainty is valid. The measurement range cannot extend below the LOQ, and it should be noted that the uncertainty at LOQ is typically ~25%.
Method precision (repeatability)	Calculated based on a series of measurements at stable concentration levels as the relative standard deviation in %.

Method accuracy

This relates to the 'trueness' of the method, which can be determined in different ways. Method accuracy can be established for each type of measurement condition (note, however, that there are many different conditions available depending on animal category, housing design, feeding, before/after air cleaner, etc.) and does not need to be included in every test. Two applicable methods are mentioned here (others are blank spiking and standard addition, but these are difficult to perform with gas measurements in barn conditions):

- Comparison with an accepted reference method according to EN14793.
  - For ammonia, the reference method would be the impinger method, according to VDI 3496 and NEN 2826.
  - For gas measurements, it is important that the sampling systems are as identical as possible.
  - According to EN 14793, the correlation coefficient r is ≥ 0.97 ($R^2 \geq 0.94$), and the slope should not differ significantly from 1, as specified in the standard.
- Comparison with a synthetic standard gas containing a certified concentration of ammonia (with a given uncertainty) in combination with tests to document that the method is free of interferences from known constituents in the matrix to be measured – relevant constituents are water vapor, carbon dioxide, methane, and volatile organic compounds (VOCs). For livestock emissions, relevant VOCs are mainly volatile carboxylic acids, volatile alcohols, and ketones. The comparison should include the complete sampling system of the field setup. The acceptance criteria of accuracy for this method is defined as follows: the regression of the comparison with a certified standard should have a correlation coefficient of r ≥ 0.97, and the slope should not differ from 1 by more than the uncertainty of the certified reference gas (max. 10%). The sum of all interferences should be <5%.

Especially important parameters related to the calibration function:

- *Sensitivity:* The slope of the calibration function in units of signal per concentration unit.
- *Linearity:* Reported as the correlation coefficient (R^2), which is typically desired to be > 0.99. Lower values can be accepted, but this will influence the method uncertainty.

Response time and sampling time:

For continuous measurements, the sampling time and frequency (measurement time on each sampling point) must be adjusted to the response time in order to ensure that the full change in response is reached and that a sufficient number of data points are achieved.

7.5.2 Primary measurement parameters

The 'primary measurement parameters' target the primary environmental pollutants emitted from the mechanical ventilation system of a livestock housing unit. In this protocol, they are ammonia, odour, and dust.

If it is known that the type of air cleaner tested does not reduce a specific parameter or only has a marginal effect on it (e.g. the odour concentration in air cleaners using sulphuric acid), or the manufacturer/applicant, for other reasons, does not want to perform measurements on a specific parameter, the manufacturer/applicant can decide to specify the cleaning efficiency as zero without taking measurements.

7.5.2.1 Measurement of ammonia

Table 3: Measurement of ammonia

Sampling conditions – Ammonia
• Minimum number and distribution of sampling days: **Test location A:** - 24 hours of continuous sampling once a week during each of the two eight-week periods. - A two-week continuous NH_3 sampling using continuous measurement methods shall be carried out within each of the two eight-week periods in times with highest loads. The continuous NH_3 measurements are to be used for establishing an N-balance. **Test location B:** - Identical to location A, but measurements on only four days during the eight-weeks winter period and six days during the eight-week summer period. - Measurement days equally spread out over the eight-week period. - In broilers: at least one sampling during the last week of the production cycle. • Parameters to be measured during each of the measurement days: air volume flow (continuously), temperature and relative humidity (before and after the air cleaner), and pH of the discharged water (at least once a week). • Samples of the recirculation liquid of the air cleaner shall be taken on all measurement days. • During the measurement, the animal occupation rate must be between 90 and 100%.
Measurement method – Ammonia
For standards for measurements, see the bibliography for details. For special requirements, see Section 7.5.1 • For N balance, online measurement systems are required. • The measurement method shall be the same for inlet and outlet air. • Gas detection tubes are not applicable and can only be used for indicative measurements.
N balance
For operational stability: • Water analyses once a week with pH electric conductivity, NH_4-N, NO_2-N, and NO_3-N (within eight-week periods). • Testing for the N balance is only allowed when the operational stability of the air cleaning system is sufficient. For N balance: • A period of at least two weeks (for biofilters: at least four weeks) within each of the eight-week periods with online gas (NH_3, NO_X, N_2O) and volumetric flow measurements (gas and liquid). • Water analyses (test location A): During the two-week continuous NH_3 measurements, the drained discharge water shall be stored in a tank. Liquid samples from the first day, a day in the middle, and the last day of the two-week period shall be taken from the air cleaner and the storage. Analyses according to the bibliography. • Calculation: see Annex C. • NO_x and N_2O measurements are not necessary for acid scrubbers. • For multistage scrubber systems, only the total N balance is required and not for the individual steps. The step of biofiltering with organic filling material should not be included in the balancing.

7.5.2.2 Measurement of odour

Table 4: Measurement of odour

Sampling conditions – Odour

- Minimum number and distribution of sampling days:
  - Test location A: Weekly, with two sets of samples per day during the eight-week summer and winter periods.
  - Test location B: Two sets of samples per day for four days during the eight-week winter period and six days during the eight-week summer period. Sampling days equally spread out over the eight-week period, with at least one sampling during the first week and one sampling during the last week.
- Sampling between 9 am and 4 pm.
- Samples for raw and clean gas have to be taken simultaneously.
- Sampling location: cross section of air outlets, preferably mixed sample.
- Sampling time: minimum 30 minutes.
- Sampling equipment: according to EN 13725.
- According to the EN 13725, the lab has to document how the risk of condensation in the sampling bags is avoided.

Parameters to be measured during the measurement days:
- Air volume flow (simultaneously and continuously with a measurement frequency < 5 min).
- Temperature
- Humidity (before and after the air cleaner) – must be >90% in clean gas to prove proper functioning of system.
- pH of discharged water (at least once a week).

Odour characteristics (optional)

- Only for samplings at test location A.
- Analysis in terms of kind of odour (e.g. pig smell or earthy) *(obligatory in Germany)*
- To define the specific odour of pigs or poultry, a team of test people, skilled according to EN 13725, are appointed. The team has to be trained on process-typical odours, resulting in qualified yes/no statements about the process-typical odour during the olfactometry measurement.

Measurement method – Odour

Olfactometry according to EN 13725: Air quality - Determination of odour concentration by dynamic olfactometry.

(Note: in NL, the use of the forced choice response method is obligatory for the Dutch 'Regeling geur en veehouderij (Regulation on odour and livestock))

7.5.2.3 Measurement of particulate matter

Table 5: Measurement of PM

Sampling conditions - Particulate matter

- Only required on test location A.
- Measurement of PM10 and a larger fraction (e.g. 'TD' and 'ID') is mandatory. PM2.5 is optional.
- A minimum number and distribution of sampling days for total dust and PM10:
- Two days in each of the eight-week periods. Sampling days should be in different weeks.
- At least two sets of samples at each sampling day, either consecutive or in parallel.
- Samples for raw and clean gas have to be taken simultaneously.
- Sampling must be isokinetic, or the air speed must be below 2 m/s.
- Sampling location: based on air velocity and homogeneity.
- Sampling time shall be adjusted to provide the detectable mass of particles: as a guideline, between 30 min and 24 hours. For short measurements, sampling shall be between 9 am and 4 pm.

Measurement method - Particulate matter

Gravimetric methods

The exact particulate matter fraction that has been sampled has to be reported, i.e. either by referring to a fraction (PM10, TSP, TD, and ID), by mentioning its 50%-cut off diameter, or by giving its cut-off curve.

Standards for measurements (see the bibliography for details), e.g.:
- EN 12341 and EN 13284-1 (for PM10 and PM2.5).
- ISO 7708 and EN481 (for inhalable dust, PM100).
- NIOSH Method 0500 (for total dust).
- 40 CFR 50, Appendix B (for TSP, PM35).

For measurements of the particulate matter, the following should be considered: when measurements are meant to produce absolute PM concentration values or absolute PM emission rates, measurement methods should produce concentrations near the true concentration. Systematic bias of measurement methods can be severe. Measurement methods can only be used after equivalence tests to relevant reference samplers have been carried out and published and corrective measures have been taken. Such measures may, for instance, include the recalibration of a method using the PM of interest or the use of correction factors. No standard is available describing how to perform equivalence tests in livestock production settings. The standards listed in the bibliography, however, provide some guidance, e.g. with regard to reference samplers, general procedures, and statistical tests. In general, standard EN 12341 provides many useful elements.

When measurements are meant to produce a PM removal efficiency on a relative scale (i.e. determined from the PM concentrations downstream and upstream of a technology), the systematic bias of a sampler (i.e. a systematic deviation of the measured concentration from the true concentration) would, in principle, be less relevant. When the exact same error is made on both sides of an air cleaning technology, this error would be cancelled out when calculating a removal efficiency. However, it is questionable whether the latter assumption can be met in practice, since the particle size distribution and air characteristics usually change when the air flow passes an air cleaning technology. These downstream changes may well give rise to errors of a different nature or magnitude. Therefore, in this situation, samplers are also needed that produce concentrations near to the true concentration.

In any case, it is recommended that concentration values at a sampling position are, in principle, taken in duplicate, since the random error between instruments of the same measurement method are relatively high in livestock production settings. This principle may be further adapted to a 'multiple single sampling' approach for situations where several single measurements are taken, spread out over a large cross-sectional area (as is often the case in filter walls, air scrubbers, biofilters, etc.). The latter approach covers both spatial variation and random error between instruments.

7.5.3 Measurement parameters representing test conditions

Table 6 shows the measurement parameters that represent the test conditions, including parameters that may influence the emission level of the primary environmental pollutants, e.g. by affecting the performance of the air cleaning system. In addition, the table includes other – secondary – environmental pollutants.

Some of the parameters for demonstrating the test conditions are mandatory, while others are optional. In the table, the mandatory and optional measurement parameters are marked with 'M' or 'O' respectively.

Table 6: Measurement parameters for representing test conditions

Parameter [Unit] M: Mandatory O: Optional	**Sampling conditions (where, how, and how often)**	**Measurement methods**
Operational function and stability (M)	Continuous measurements of key parameters for functioning	See Annex A
Ventilation rate (M) [m^3 h^{-1}]	Ventilation rate through the air cleaner. Continuous measurements. In housing units with partially air cleaning, the ventilation rate must also be measured for the untreated air.	Fan wheel anemometer, covering the whole outlet before the ventilator. Requirements of fluid mechanics must be respected, i.e. sufficient distance between the ventilator and the anemometer (see EN 15259 for advice and details).
Number and weight of animals in the housing unit (M) [kg]	Date, number, and weight of animals when they are inserted and taken out of the housing unit.	Weighing and housing diary.
N_2O (M for biological systems only) [mg m^{-3}]	Continuous measurement during the N balance.	e.g. FTIR and GC-ECD.
NO_x (M for biological systems only) [mg m^{-3}]	Continuous measurement during the N balance.	e.g. Chemiluminescence.

Parameter [Unit] M: Mandatory O: Optional	Sampling conditions (where, how, and how often)	Measurement methods
Temperature (M) [°C]	• Continuous measurements. • Sampling location: air inlet and air outlet.	Thermo couples. Adequate measuring range, sensitivity, and detection limit. Consider undesired effects on measuring device through, e.g., contaminations, wind, or direct sunshine.
Humidity (M) Relative humidity [%]	• Spot measurements during the measurement days for odour. • Sampling location: air inlet and air outlet.	Capacity sensor. Consider undesired effects on measuring device through, e.g., contaminations, wind, water, direct sunshine, or frost.
Pressure loss (M) [Pa]	Across the air cleaner alone and across the entire ventilation system including the air cleaner. Continuous measurements.	Manometer, electronic micro manometer (difference pressure across membrane).
Consumption of electricity (M) [kWh]	Continuous measurement of 1) electricity consumption by ventilation in general, and 2) by the pumps in the air cleaning system.	Both measurements every second week.
Consumption of water (M) [l], [m³] Related to time	Cumulative measurement.	Documentation.
Consumption of chemicals (e.g. acid) (M) [mg or kg] mass [l or m³] volume	Cumulative measurement.	Documentation.
Discharged liquid from the air cleaner Amount (M) pH (M) Conductivity (M) NH_4^+ (M) NO_2^-/NO_3^- (M) Chemicals (those added to the air cleaner) (M)	Immediately after sampling, the samples must be stored at temperatures < 5°C.	For methods, see the bibliography.
Emptying of the pits or manure channels (M)	Register dates.	Documentation.
Cleaning of animal house and dunging behaviour (M)	Description of cleaning procedure. Registration of dunging behaviour in each pen on days with odour sampling.	Documentation.
Feeding parameters (M)	During the testing period, the dietary protein contents should be within specific ranges for different pig categories and poultry. See Annex D.	Documentation.
Noise (O)	Outdoor 1-2 m from ventilation outlet.	Noise level meter ISO 3746.
NH_3 (O) at animal level [ppmv]	At animal level (height of the animal's nose).	Gas detection tubes, or see methods for ammonia.
CO_2 (O) [mg m^{-3}]	See 'ammonia' and 'general recommendations' above.	
CH_4 (O) [mg m^{-3}]	See 'ammonia' and 'general recommendations' above, or combined with odour sampling.	
H_2S (O) [mg m^{-3}]	Combine with odour sampling.	e.g. GC-SCD.

7.6 General aspects

7.6.1 Animal health and welfare

The air cleaner is directly connected to the ventilation system in the housing unit. Therefore, the air cleaner will have a direct impact on the climate in the housing unit and on the health and welfare of the animals. Generally, the housing system, the climate in the housing unit, and the welfare of the animals must be in compliance with national regulations. Since the air cleaning system can affect the welfare of the animals and can, in extreme cases, result in death among the animals, the companies that install the systems should be able to demonstrate that they are experts in ventilation and climate control in animal housing units. The systems shall be designed, operated, and controlled in such a way that animal health and welfare are not negatively affected. Furthermore, the test institute must also be able to assess the entire air cleaning system and not just the individual air cleaner.

Recommendations on the proper design and operation for avoiding problems are further illustrated in Annex E.

7.6.2 Regulations and occupational health and safety

When performing a test according to this test protocol, all activities shall be carried out in compliance with relevant national and EU legislation, as well as relevant standards.

In general, air treatment systems – as for all industrial machinery and equipment – must comply with the Machinery Directive (Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC [recast]). They must be designed and constructed in such a way that they can be used, adjusted, and maintained throughout all phases of their life without putting people at risk.

In detail, the installations must satisfy the essential safety requirements contained in Annex I of the Directive, a correct conformity assessment must be carried out, and a 'Declaration of Conformity' must be given.

It is the responsibility of the manufacturer/applicant, importer, or end supplier of the equipment to ensure that equipment supplied is in conformity with the Directive. In addition, Council Directive 89/655/EEC of 30 November 1989 concerns the minimum safety and health requirements for the use of work equipment by workers at work (amended 2007/30/EC) and places obligations on businesses and employers to take into account potential dangers to operators and other people using or affected by machines and equipment.

In general terms, the directive requires that all equipment provided for use at work is suitable and safe for the intended use; maintained in a safe condition and, in certain circumstances, inspected to ensure this remains the case; used only by people who have received adequate information, instruction, and training; and accompanied by suitable safety measures, e.g. protective devices, markings, and warnings.

In addition, ISO 12100: *Safety of Machinery* defines technical principles to help designers achieve safety in the design of machinery.

The obligations mentioned above must generally be applied, especially with respect to the chemical washers and the chemical stages of multiple-stage installations operated with inorganic acids, such as sulphuric acid, although the acid is strongly diluted in the washing stages.

The safety instructions must be documented in a safety data sheet and observed carefully.

In addition to design and construction of all installations in such a way that they can be used, adjusted, and maintained throughout all phases of their life without putting people at risk, good ventilation and appropriate protective equipment, such as acid-resistant protective clothing and eye protection, are required. Moreover, one must make sure that protective installations, such as eye wash and shower units, are available and work properly.

Additionally, chemical washers and the chemical stages of multiple-stage installations should first be rinsed thoroughly with water after they have been shut down. In these installations, acid and salt residues deposit on the highly porous lamellas as well as on other filter walls. These residues must be removed.

Lists of relevant EU directives, as well as international standards within these fields, are available in the bibliography of this test protocol and on the VERA website, at http://www.vera-verification.eu/en/technology-manufacturers/test-protocols/ under 'Links to EU directives and international standards'. Note that this list may not be exhaustive and that national legislation and standards are not included.

7.7 Data treatment, calculation, and evaluation of emissions

For each measurement parameter, the necessary units expressing the results are specified to ensure the highest possible comparability of the results and a sufficient information basis for recalculating, reproducing, converting, and relating values.

Due to the fact that different countries have different demands for how the performance of an air cleaning system is to be evaluated, the results for ammonia, odour, and dust as a mean value (including the standard deviation for ammonia) and the removal efficiency are to be provided.

When calculating the mean values and the removal efficiencies, the following conditions must be taken into consideration:

1. Calculating daily means (PM and odour)

Particulate matter ('PM' or 'dust')
For particulate matter, the removal efficiencies are calculated for each measurement day in a first step:

Mean PM removal efficiency for each measurement day (%) =

$$100 * \frac{\text{mean PM concentration [mg m}^{-3}\text{] in raw gas} - \text{mean PM concentration [mg m}^{-3}\text{] in clean gas}}{\text{mean PM concentration [mg m}^{-3}\text{] in raw gas}}$$

Odour
The odour concentration for each sampling day is to be related to the air volume flow first:
Odour load (OU_E h^{-1}) = Odour concentration (OU_E m^{-3}) * mean exhaust air volume flow (m^3 h^{-1}).

Mean odour removal efficiency for each measurement day (%) =

$$100 * \frac{\text{daily mean of odour load [}OU_E\text{ h}^{-1}\text{] in raw gas} - \text{daily mean of odour load [}OU_E\text{ h}^{-1}\text{] in clean gas}}{\text{daily mean of odour load [}OU_E\text{ h}^{-1}\text{] in raw gas}}$$

2. Calculating the removal efficiency per test period (ammonia, PM, and odour)

Ammonia
The ammonia removal performance for the testing period can be calculated on the basis of a mass balance using the measurements of both the ammonia concentrations (e.g. mg m^{-3}) and the air flow rate (e.g. m^3 $hour^{-1}$) during the test periods (i.e. winter and summer).

For each measurement interval (e.g. 1 minute), the NH_3 load in the raw gas is calculated as follows:

$$Load\ NH_{3\_raw\ gas}\ (kg) = C_{raw\ gas}\ (kg\ m^{-3}) * Q\ (m^3\ h^{-1})$$

Where:
$C_{raw\ gas}$ (kg m^{-3}) = mean NH_3 concentration of the raw gas of each time interval
Q (m^3 h^{-1}) = mean air flow rate of each time interval

If the measured $C_{raw\ gas}$ is below the quantification limit, the quantification limit is used for the calculations instead of the measured value. The outlet load, load in clean gas ($LoadNH_{3\_clean\ gas}$), is calculated in a similar way.

At the end of the test period (either winter or summer), all values of the NH_3 load in raw gas are summarised, resulting in a cumulative load ($CumLoadNH_{3\_raw\ gas}$). The same is done for the NH_3 load in the clean gas. Based on these two numbers, the average NH_3 removal efficiency is calculated as follows:

$$\textit{Removal efficiency per test period (\%)} = 100 * \frac{CumLoadNH_{3\_raw\,gas}\,(kg) - CumLoadNH_{3\_clean\,gas}\,(kg)}{CumLoadNH_{3\_raw\,gas}\,(kg)}$$

Where:

$CumLoadNH_{3\_raw\,gas}$ = sum of calculated load in raw gas for each test period
$CumLoadNH_{3\_clean\,gas}$ = sum of calculated load in clean gas for each test period

PM and odour

Based on the daily means for particulate matter and odour, and based on the mean of each test period for ammonia, means are calculated separately for each test location (A and B) and for each test period (summer and winter).

The respective standard deviation for ammonia is to be reported.

Calculating the removal efficiency per test location

$$\text{Removal efficiency for test location X (\%)} = \frac{\text{winter removal efficiency + summer removal efficiency}}{2}$$

Calculating the verified removal efficiency

$$\text{Verified removal efficiency (\%)} = \frac{\text{mean removal efficiency location A + mean removal efficiency location B}}{2}$$

It is very important that the exhaust air flow rates, especially in summer, are registered during the measurements in order to be able to verify the corresponding filter area loads.

In the verification statement, the removal efficiency must be stated in % at the maximum filter area load in [$m^3\,m^{-2}\,h^{-1}$]. The verified maximum filter area load may vary depending on the parameter (i.e. ammonia, dust, and/or odour). The advantage of this description is that, depending on the demands placed on the air cleaning system, the manufacturer and approval authorities can precisely check the corresponding filter system with regard to the total filter area.

8. Test report and evaluation

This section describes the requirements for the test report, including formalities for system and test description, data handling, and statistical analysis.

Generally, the test results shall be reported on the basis of EN 15259 *Air quality – Measurement of stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report.*

The test report must be written in English and, if necessary, in the local language. The report must include chapters with the subheadings listed below. The following paragraphs provide a description of the contents that must be included in the chapters and suggestions for the contents of the individual sections.

Foreword

The foreword should include:

- a description of the three parties involved in the test – the applicant, the test body, and the farmer/s – and their respective roles during the test period;
- specification of the test period, including dates;
- date and signatures of the person(s) responsible for the test; and
- name and address of the test body.

Introduction

The introduction may contain a motivated description of how the system/technology tested can meet the environmental challenges by decreasing emissions of environmental pollutants, thereby reducing the overall environmental effect of the agricultural production system in question.

In addition, the introduction must include a description of the applicant/manufacturer involved in the test and provide a general description of their application technology system. If the applicant/manufacturer has performed previous tests, these must be described and references provided.

Material and methods

The materials and methods section shall include a description of:

- the farms involved in the test;
- the air cleaning system, including the requirements for proper operation;
- the measurement method, including measurement uncertainty; and
- the housing unit in which the test is performed.

The description shall include the

- animal category;
- number of sections that are connected to the air cleaning system;
- dimensions of the sections and pens;
- number of pens per section; and
- number of animals per section.

In addition, the type of floor, dunging system, feed system, and ventilation system shall be described. Photos taken inside the sections and photos of the housing unit shall be included in the test report.

The description of the housing unit shall be followed by a description of the air cleaner, dimensioning criteria, and control principle, as well as a description of how the air cleaner is connected to the ventilation system. More specific details can be included in an appendix. The test report must also include photos and any drawings of the air cleaning system.

The description of the air cleaner shall be followed by a description of the test design, the dimensioning of the test, and the measurement methods, including a specification of the measurement instruments used, the measurement points, and the measurement frequency and calibration procedures. Furthermore, the test report shall include a description of the statistical data processing method, including models and the statistical software package used.

Results

The description of the results starts with a specification of the measured primary parameters (odour, ammonia, and dust concentrations, cf. Tables 3 to 5) that are the primary targets of the test. The individual raw data shall be shown first in graphs, and subsequently the processed data shall be given in tables with medians, averages, and 95th percentiles.

To demonstrate the odour, the data should be presented for each measurement day, with the relevant corresponding data describing the measurement conditions as shown in the following table:

Odour measurement	
Date	Date of the individual measurement day
Animals	Number of animals on the measurement day
Animal weight	Average weight of the animals on the measurement day
Ambient and boundary condition	
Outside temperature	Mean in °C during sampling time
Outdoor humidity	Mean in % during sampling time
Raw and clean gas temperature	Mean in °C during sampling time
Raw and clean gas moisture	Mean in % during sampling time
ø exhaust air volume flow	Mean in $m^3\ h^{-1}$ during sampling time
ø filter surface load	Mean in $m^3\ m^{-2}\ h^{-1}$ during sampling time
Odour concentration	
Raw gas concentration	Geometric mean of the individual samples
Clean gas concentration	Geometric mean of the individual samples

After the presentation of the raw data, a discussion of the results shall be given.

The average and standard deviation of the measurement parameters for demonstrating the test condition (cf. Table 6), and of any supplementary measurement parameters, shall be shown in tables and commented on in the text.

A mass balance for nitrogen shall be shown if applicable, cf. Annex C.

An evaluation of the operating stability of the system shall be given. This evaluation shall be based on observations made during the entire testing period and shall include all recorded data describing the stability of the air cleaning system.

The uptime of the technology during the test period shall be calculated as well as the efficiency of the technology corrected by the uptime factor *(Example: if the cleaning efficiency of a technology is 90% and the uptime is 80%, the corrected efficiency of the technology is 72%).*

Furthermore, the test report shall include an evaluation of the potential risks that may be related to the use of the system, including any potential impact on:

- the health and welfare of the animals;
- occupational health and safety; and
- the total (external) environment.

These evaluations shall include situations with normal operation of the air cleaning system and any unforeseen use and problem.

The test report shall include advice to the authorities on how to inspect the system, cf. Annex B: Monitoring and documentation of operation.

Finally, the test report shall include an evaluation of how the results can be applied to other types of animal housing units or other animal categories (cf. Annex E).

Conclusion
The conclusion describes and discusses the test results and validates the air cleaner in general. The conclusion chapter shall include only those aspects that can be justified in the results chapter in the test report.

References
Relevant references to be specified.

Annexes
Annexes can be added if relevant.

9. Bibliography

Standards applied:

General

Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast).

Council Directive 89/655/EEC of 30 November 1989 (amended 2007/30/EC) on minimum safety and health requirements for the use of work equipment by workers at work.

EN ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories.

EN 15259 Air quality – Measurement of stationary source emissions – Requirements for measurement sections and sites and for the measurement objective, plan, and report.

EN 12599 Ventilation for buildings – Test procedures and measuring methods for handing over installed ventilation and air conditioning systems.

EN ISO 12100 Safety of machinery – General principles for design – Risk assessment and risk reduction.

EN 82079 Preparation of instructions for use – Structuring, content, and presentation.

ISO 3600 Tractors and machinery for agriculture and forestry – Operator's manuals and technical publications – Presentation.

KTBL (2008) Exhaust Air Treatment Systems for Animal Housing Facilities. KTBL Publication 464, Darmstadt.

IMAG (2002) Meetmethoden gasvormige emissies uit de veehouderij (Measurement methods for gaseous emissions from livestock production), IMAG-rapport 2002-12, Wageningen.

Measurement of particles

ISO 7708 Air quality – Particle size fraction definitions for health-related sampling.

EN 481 Workplace atmospheres – Size fraction definitions for measurement of airborne particles.

EN 12341 Ambient air – Standard gravimetric measurement method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter.

EN 13284-1 Stationary source emissions – Determination of low range mass concentration of dust - Part 1: Manual gravimetric method.

EN 13284-2 Stationary source emissions – Determination of low range mass concentration of dust - Part 2: Automated measuring systems.

NIOSH Method 0500 Particulate not otherwise regulated, Total aerosol mass, *Manual of Analytical Methods (NMAM),* Fourth Edition.

40 CFR Appendix B to Part 50 Reference method for the determination of suspended particulate matter in the atmosphere (high-volume method).

VDI 2066 Blatt 1-7, Messen von Partikeln; Staubmessungen in strömenden Gasen.

VDI 2066 Blatt 10, Ausgabe: 2004-10 Messen von Partikeln - Staubmessung in strömenden Gasen - Messung der Emissionen von PM10 und PM2,5 an geführten Quellen nach dem Impaktionsverfahren.

Measurement of odour

EN 13725 Air quality – Determination of odour concentration by dynamic olfactometry.

VDI 3940 Blatt 1-5, Ausgaben: 2006-2013 Bestimmung der Geruchsstoffimmission durch Begehungen.

Measurement of Ammonia

prEN ISO/DIS 21877 Stationary source emissions – Determination of the mass concentration of ammonia – Manual method.

NEN 2826 Air quality – Stationary source emissions – Sampling and determination of gaseous ammonia content.

VDI Guideline VDI 3496, Blatt 1 Gaseous emission measurements. Determination of basic nitrogen compounds sizeable by absorption in sulphuric acid.

KTBL (2001) Messmethoden für Ammoniakemissionen. KTBL-Schrift 401, Darmstadt.

IMAG (2002) Meetmethoden gasvormige emissies uit de veehouderij (Measurement methods for gaseous emissions from livestock production), IMAG-rapport 2002-12, Wageningen.

Analysis of effluent water

Ammonium Nitrogen:

EN ISO 11732 Water quality – Determination of ammonium nitrogen – Method by flow analysis (CFA and FIA) and spectrometric detection.

EN ISO 14911 Water quality – Determination of dissolved Li^+, Na^+, NH_4^+, K^+, Mn^{2+}, Ca^{2+}, Mg^{2+}, Sr^{2+} and Ba^{2+} using ion chromatography – Method for water and waste water.

DIN 38406-5 Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung; Kationen (Gruppe E); Bestimmung des Ammonium-Stickstoffs (E 5) (German standard methods for the examination of water, waste water and sludge; cations (group E); determination of ammonia-nitrogen (E 5)).

Nitrite Nitrogen:

EN 26777 Water quality – Determination of nitrite – Molecular absorption spectrometric method.

EN ISO 10304-1 Water quality – Determination of dissolved anions by liquid chromatography of ions – Part 1: Determination of bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulphate.

EN ISO 13395 Water quality – Determination of nitrite nitrogen and nitrate nitrogen and the sum of both by flow analysis (CFA and FIA) and spectrometric detection.

Nitrate Nitrogen:

EN ISO 10304-1 Water quality – Determination of dissolved anions by liquid chromatography of ions – Part 1: Determination of bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulphate.

EN ISO 13395 Water quality – Determination of nitrite nitrogen and nitrate nitrogen and the sum of both by flow analysis (CFA and FIA) and spectrometric detection.

DIN 38405-09-2/9-3 Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung; Anionen (Gruppe D); Bestimmung des Nitrat-Ions (D 9) (German standard methods for examination of water, waste water and sludge; anions (group D), determination of nitrate ion (D9)).

DIN 38405-29 Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung - Anionen (Gruppe D) - Teil 29: Photometrische Bestimmung von Nitrat mit Sulfosalizylsäure (D 29); ISO 7890-3:1988, modifiziert (German standard methods for the examination of water, waste water and sludge - Anions (group D) - Part 29: Spectrometric determination of nitrate with sulfosalicylic acid (D 29); ISO 7890-3:1988, modified).

Gas analysis

Methods:

EN 14792 Stationary source emissions – Determination of mass concentration of nitrogen oxides (NO_X) – Reference method: Chemiluminescence.

VDI Richtlinie 3496 Blatt 1 Messen gasförmiger Emissionen; Bestimmung der durch Absorption in Schwefelsäure erfaßbaren basischen Stickstoffverbindungen (Gaseous emission measurement; determination of basic nitrogen compounds sizeable by absorption in sulphuric acid.

Annexes

Annex A (mandatory): Decisive design and operational parameters

The description of the air cleaning system to be tested shall include a list of the essential design and operational parameters (ranges) that are specific to the system and are decisive for proper functioning.

The description shall include the parameters listed below (blue text indicates examples). The relevant parameters depend on the cleaning principle; the largest differences occur between biofilters and other systems.

Annex A1: Mandatory decisive design and operational parameters (single stage biofilters)

(blue text indicates examples)

Table 7: Design parameters – single stage biofilters

System description	(single stage biofilter with fresh water supply)		
Filter material	(root wood or wood chips)		
Filter material additives	(microorganism, fertilizers, or buffer substances)		
Suitability	(pig production: particulate matter and odour reduction, slurry-based/littered system, ventilation system)		
Total system	**Unit**	**Data**	**Additional information**
Kind and weight of animals	kg	X	
Maximum animal places (AP)	-	X	
Maximum air flow	$m^3\ h^{-1}$	X	
Specific water consumption	$m^3\ AP^{-1}\ year^{-1}$	X	
Maximum total pressure drop	Pa	X	
Length/width/height	m	X	(Layer 1, inlet section: 10 x 10 x 0.2) (Layer 2, outlet section:10 x 10 x 0.8)
Max. surface load	$m^3\ m^{-2}\ h^{-1}$	X	
Max. volume load	$m^3\ m^{-3}\ h^{-1}$	X	
Number of irrigation nozzles	-	X	
Water pressure of irrigation system	bar	X	
Irrigation	$m^3\ h^{-1}$	X	(Five minutes per hour)
Irrigation density	$m^3\ m^{-2}\ h^{-1}$	X	
Filter material	**Unit**	**Data**	**Additional information**
Filter material	-	X	(root wood or wood chips)
Thickness (range)	mm	X	
Filter material additives	-	X	(microorganism, fertilizers or buffer substances, data sheet)
Lifetime of filter material	years	X	

Annex A 2: Mandatory decisive design and operational parameters (air scrubbers and air scrubber stages)

(blue text indicates examples)

Table 8: Design parameters – air scrubbers

System description	(single stage trickling filter)				
Suitability	(pig production: ammonia, particulate matter and odour reduction, slurry-based/littered system, ventilation system)				
Total system	**Unit**	**Data**	**Additional information**		
Kind and weight of animals	kg	x			
Maximum animal places (AP)	-	x			
Maximum air flow	$m^3 h^{-1}$	x			
Dwell time	s	x	(total system)		
Specific water consumption	$m^3 AP^{-1} year^{-1}$	x			
Specific water discharge	$m^3 AP^{-1} year^{-1}$	x			
Maximum total pressure drop	Pa	x			
Specific acid consumption	$m^3 AP^{-1} year^{-1}$	x	(96% sulfuric acid)		
Specific alkali consumption	$m^3 AP^{-1} year^{-1}$	x	(50% sodium hydroxide)		
Specific additive consumption	$m^3 AP^{-1} year^{-1}$	x	(Defoamer: product xx (specified by data sheet))		
Packing	**Unit**	**Stage 1**	**Stage 2**	**Stage 3**	**Remarks**
		Data sheet	Data sheet	Data sheet	Description if no data sheet is available
Length/width/height	m	x	x	x	
Specific surface area	$m^2 m^{-3}$	x	x	x	
Max. surface load	$m^3 m^{-2} h^{-1}$	x	x	x	
Max. volume load	$m^3 m^{-3} h^{-1}$	x	x	x	
Sprinkling	$m^3 h^{-1}$	x	x	x	
Sprinkling density	$m^3 m^{-2} h^{-1}$	x	x	x	
Volume water basin	m^3	x	x	x	
pH range	-	min - max	min - max	min - max	
Max. conductivity	$mS cm^{-1}$	x	x	x	
Droplet eliminator	**Unit**	**Data sheet**			**Description if no data sheet is available**
Length/width/height	m	x			
Max. air velocity	$m s^{-1}$	x			

Annex B (informative): Electronic monitoring and documentation of exhaust air treatment operation

All exhaust air cleaning systems shall be equipped with electronic data logging that records data relevant for operations and mainly serves to document the proper operation of the exhaust air cleaning system.

Depending on the national regulations, it can be mandatory to provide certain data recordings to local authorities.

Parameters to be recorded in this data logging are listed in the following table for the different cleaning techniques and countries:

Parameter	Unit	Germany (depending on region)		The Netherlands	Denmark
(X = obligatory)		Biofilter	Trickling filters, scrubbers, and multi-stage operations		
Air flow	$m^3\ h^{-1}$	X	X		Requirements in DK will be specified by the local authority and may include some of the listed parameters.
Total pressure drop	Pa	X	X	X	
Total cumulative fresh water consumption	m^3	X	X		
Total cumulative power consumption	kWh	X	X	X	
Running time of sprinkling/irrigation pumps	time	X	X		
Total cumulative water discharge	m^3		X	X	
pH-Value	-		X	X	
Electric conductivity	$mS\ cm^{-1}$		X	X	
Raw gas temperature	°C	X	X		
Outside temperature	°C	X	X		
Clean gas temperature	°C		X		

Additional manual records may include:

- control of irrigation system/sprinkling pattern;
- calibration of pH and conductivity sensors;
- maintenance and repair times, including kind of work;
- exchange of filter materials (time and frequency); and
- water pressure of the in-house water supply.

Operational data, such as pressure loss and air rate, the running times of the pumps, and the sprinkling intervals, as well as data regarding the consumption of freshwater and acid (if applicable) and the quantity of wastewater, are generally relevant and should be archived, at least, in hourly intervals.

In individual cases, it may be necessary to document additional parameters besides those listed in the table above. In particular, this also applies to exhaust air cleaning techniques that cannot be classified as a variant of one of the described techniques. Methods such as oxidising exhaust air cleaning, which cleans the air with the aid of additives, would fall under this category. In this case, the additive quantities consumed would have to be recorded in a suitable form.

The data of the electronic operations logbook helps farmers to run their installations efficiently and in a cost-effective manner. If pressure losses grow due to improper operation, for example, while the air volume flow remains constant, this leads to significant additional energy costs, which could be avoided. Significantly higher acid consumption values also show that the exhaust air cleaning system is operated improperly and, hence, causes unnecessary expenses. If maintenance contracts are concluded, these costs decrease if any of the potential faults are detected because the information needed for the elimination of the malfunctions is available immediately.

In addition, the electronic operations data logging allows the farmer to prove the proper operation of the installation at any time if neighbours complain or if such proof is required by the supervising authority, which significantly improves legal security.

Annex C (mandatory): Nitrogen balance

Air cleaning technologies used in animal husbandry shall not contribute to secondary trace gases that may create stronger environmental impacts than the raw gas compounds itself. For biological processes with ammonia oxidation, an unintentional transformation of ammonia into NO and N_2O may occur to some degree, and this needs to be documented.

With a nitrogen balance of air cleaning technologies, the following goals should be achieved:

Documentation of all relevant processes within the air cleaning system.

Documentation of possible secondary trace gases with a very high global warming potential (N_2O) or contributing to tropospheric ozone formation (NO).

Securing a long operating air cleaning technology by nitrogen mass equation.

For the nitrogen balance of an air purification system, all the possible mass flows indicated in Figure 1 have to be considered in principle.

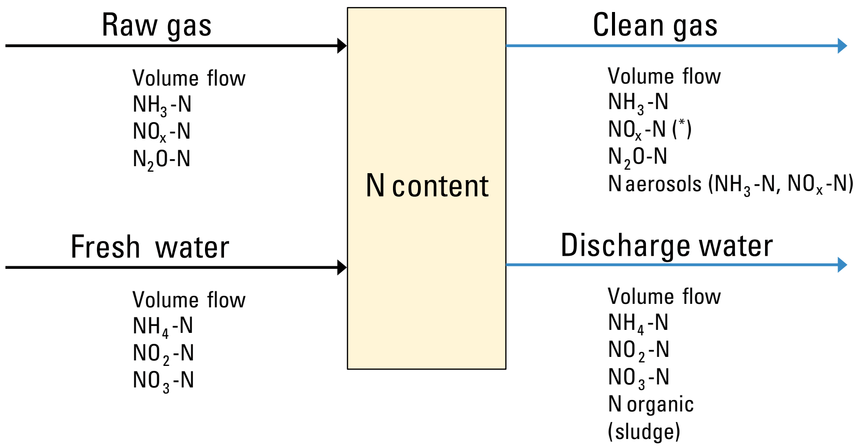

Figure 1: Overview of mass flows of N compounds in an air cleaning system

(*) Comment to NO_x-N in clean gas: for biological filters, if the pH becomes < 6, there is a risk that significant amounts of HNO_2 will be released into the exhaust air by evaporation. This gaseous HNO_2 will be falsely measured by a chemiluminescence instrument as NO_2 and thus wrongly included in the nitrogen balance as 'NO_x'. NO_x is defined as NO and NO_2, but chemilumiscence instruments with a reductive converter for measuring NO_2 will, in fact, measure other oxidised nitrogen compounds, including HNO_2. For the nitrogen mass balance, any measured quantities of 'NO_2' should be included, but this should be reported as 'evaporated HNO_2'. This is only relevant for the condition that the pH is less than 6, which has been observed for certain biotrickling filters.

The question of whether a nitrogen balance is required depends on the kind of technology used for air cleaning. For instance, it is not necessary for mechanical dust separation systems.

For chemical scrubbers with low pH values in the washing liquid, it is reasonable to get information on aerosol discharge and precipitation processes (e.g. the filling material and droplet separator) within the system. Normally, only reduced nitrogen compounds such as NH_3 and NH_4^+ have to be considered for balancing chemical scrubbers.

In contrast, a nitrogen balance for biological operating air cleaning systems is more complex and should comprise the data mentioned in Figure 1. Biotrickling filters and conventional biofilters with an organic filter material can significantly contribute to secondary trace gas emissions if there is no sufficient water discharge (biotrickling filters) or change of material (biofilters).

The basic requirements to be fulfilled for an N balance are also listed in Section 7.5.2.1

The measurements should be carried out in the last four weeks of the measurement periods. In broilers, the winter measurements should cover the first half of the batch to get the lowest emission level.

In order to evaluate the retention of all nitrogen components within the N-deposition, all nitrogen inputs into the system, as well as all nitrogen emissions from the system, including the aerosol discharges and the nitrogen mass enriched in the wash water and sludge, are measured during the two-week balancing period and evaluated.

In addition, the input and output air volume flow are continuously recorded and stored as half-hour mean values.

Examples of an N balance:

Example: Chemical cleaner

In consideration of the gaseous nitrogen inputs and outputs, as well as the enrichment of nitrogen in the process water, a balance has been created during the measurement period. To allow for the use of the gas concentrations with the test instrument used, the raw gas concentrations (NH_3) must be ≥ 3.3 ppm.

Additional gaseous nitrogen compound concentrations were below the detection limit and will not be considered here. It should be noted that the nitrogen ligated in the process water can only be determined with a relatively high measurement uncertainty. The analysis of the samples is very precise; however, the actual process water volume in the system at the sampling time cannot be easily determined (i.e. the accuracy of level measurement is low).

Table 9: Example of an N balance

Input [kg]	NH_3-N raw air	101.0
	Raw air $_{\text{additional gaseous N compounds}}$	0.0
	Amount IN	101.0
Output [kg]	DELTA $N_{inorganic}$ process water	38.1
	$N_{inorganic}$ discharge water	47.5
	NH_3-N clean air	9.1
	Clean air $_{\text{additional gaseous N compounds}}$	0.0
	Amount OUT	94.7
Difference	IN – OUT	6.4
Recovery rate [%] total	OUT/IN	94
NH_3 reduction rate	(IN-OUT)/IN	0.91
$N_{gaseous}$ reduction rate	(IN-OUT)/IN	0.91

From the 101 kg NH_3-N input, 85.6 kg was recovered in the process water and in the discharge water of 01.01.1900. This corresponds to a removal rate of 85%.

However, the increased measurement uncertainly for the process water volume determination must be considered.

N elimination

To determine the N elimination, the gaseous nitrogen input will be set in relation to the enriched nitrogen in the system.

- *To determine the gaseous input, the half-hourly mean values of the measured concentrations and the relevant volume flows are linked to the N load.*
- *To determine the enriched nitrogen in the system, the N content in the process water as well as the process water volume is identified at the beginning and end of the balance, and the difference thereof is calculated.*

Due to the significant measurement uncertainty when identifying the process water volume, this determination of the enriched nitrogen in the system can demonstrate problems. Furthermore, it must be considered that depositions in the system may occur that are not visible from the outside and will be eliminated during cleaning. These components were eventually removed from the gaseous input and would need to be considered appropriately.

When no significant transformations of NH_3 to secondary compounds occur, the raw and clean gas concentrations can be directly compared with each other, and the gaseous N elimination can be determined from the removal rate.

Annex D (informative): Agronomic recommendations

Gas concentrations inside the test house

Table 10: Gas concentrations inside the test house

Gas	Allowed range	Animal category
CO_2	< 3000 ppm	Pig, poultry, calves
NH_3 at animal level	< 20 ppm	Pig, poultry, calves
NH_3 in raw gas	< 30 ppm	Pig, poultry, calves
H_2S	< 5 ppm	Pig, poultry, calves

Agronomic conditions

For all animal categories:

Animal welfare	Production must be in compliance with national animal welfare regulations (see Annex E).
Animal occupation rate of test compartment at all measurement days	90-100%

Table 11: Feeding requirements per animal category

Animal category	Feed composition/Crude protein (CP) needs	
Cattle	≥ 50% roughage ≥ 160 g (or 160 – 180 g) CP/kg dry matter *(NL: milk urea content of ≥ 15 mg per 100 g)*	
Sows	Pregnant: 11-14% CP Lactating: 13-17% CP	
Pigs – weaners	< 20 kg: 18-21% CP > 20 kg: 17-20% CP	
Fattening pigs	< 50 kg: 15-18% CP > 50 kg: 14-16.5% CP	
Poultry	**Danish recommendations**	**German recommendations**
Laying hens	16-18% CP	15-20% CP
Broilers	35-40 days/1.6-3 kg: 20-21% CP; 56 days/2.4 kg: 15% CP	17-23.5% CP
Ducks	4 kg live weight: 17% CP	Week 1-2: 20-24% CP Week 3-7: 16-18% CP
Turkeys	10 kg live weight: 20% CP 20 kg live weight: 18% CP	Week 1-5 (starter): 26-29.5% CP Week 6-16 (females): 18-24.5% CP Week 6-21 (males): 14-24.5% CP
Geese	7 kg live weight: 16% CP	

Annex E (informative): Animal welfare and the air cleaning system

It is recommended that the test institute and the manufacturer or company that install the air cleaning system are able to demonstrate theoretical and practical knowledge of:

- thermal comfort for animals;
- climate control in animal housing units;
- design of the ventilation duct system;
- electronic control of the ventilation system in the entire housing unit;
- regulatory demands and safety recommendations relating to the alarm system;
- project management; and
- spoken and written advice for the farmer and his employees.

A number of examples on how connecting the air cleaner to the ventilation system in the housing unit could have a negative effect on the welfare of the animals are described in the following paragraphs, so that companies that connect air cleaners to the ventilation system can learn from previous mistakes. The test institute can also use the descriptions when they assess the entire air cleaning system.

The following points will be described in detail:

- different air qualities in the individual pens;
- air exchange in the housing unit in general;
- fluctuations in the ventilation flow and temperature level;
- problems with the air inlet in housing units with diffuse air intake through the ceiling;
- emergency ventilation in the housing unit in connection with power failures;
- tail biting;
- increased respiratory problems among the animals;
- reduced thermal comfort; and
- reduced productivity and, in extreme cases, death among the animals.

Different air qualities in the individual pens

The housing units have previously been ventilated by a number of fans placed at regular distances from each other throughout the housing unit. When connecting the air cleaner to the ventilation system, some companies have reduced the number of outlets, either due to a lack of knowledge or in order to reduce the installation costs.

This has resulted in an inconsistent air quality in the individual section. The animals placed farthest away from the outlet had a reduced air quality, with greater ammonia and carbon dioxide concentrations.

Air exchange in the housing unit in general

One of the general problems for the housing unit is that the air exchange in the individual section is reduced as a result of gradual clogging of the filter.

Gradual clogging can occur due to an accumulation of dust particles in the filter. However, clogging can also occur during a shorter period (e.g. a few days) due to the rapid growth of microorganisms in the filter.

All previous tests have demonstrated that clogging of the filters will happen. As a consequence, the companies must have a plan for how clogging problems should be handled. For example, automatic systems for systematic cleaning of the filters could be a solution. Alternatively, manual washing supplemented with an alarm system could also be a solution. The alarm could be controlled by the pressure drop across the filter, depending on the air flow through the filter.

Problems with the air inlet in housing units with diffuse air intake through the ceiling

The air cleaner can be connected directly to the individual section, or there can be a larger air cleaner that treats the air from several sections. If the air cleaner treats the exhaust air from several sections, a central duct connecting the air cleaner and the outlets in the section must be installed.

In Denmark, most of the facilities for weaners and finishers are installed with diffuse ventilation with air intake through the ceiling. The central duct is often located in the attic, and it is very important that the distance between the diffuse air intake and the duct is sufficiently large to allow a uniform flow of fresh air through the ceiling.

Emergency ventilation in the housing unit in connection with power failures

The legislation stipulates that an alarm system must be installed in cases of power failure or other types of ventilation failure. In traditional housing units without air cleaners, a damper in the outlet automatically opens to provide natural ventilation. If an air cleaner is installed, the pressure loss will be increased, which will prevent natural ventilation. In housing units with air cleaners, other types of emergency openings must be installed.

Filters in air cleaners can become clogged with dust, fungal growth, or other microfilm. It would be an advantage to automatically record the ventilation rate and the pressure loss over the filter. The system control could use this data to give an alarm when the filters start to become clogged.

Reduced productivity, tail biting, thermal comfort, and, in extreme cases, respiratory problems and death among the animals

If the air cleaner is not correctly connected to the individual section, there will be a risk of reduced productivity and thermal comfort. In extreme cases, draughts in the pens and reduced air exchange could result in stress, tail biting, and increased respiratory problems. There are also some examples of where the animals in the entire housing unit died because of ventilation failure. Normally, ventilation failure will only affect the animals in one section. However, in housing units with central ventilation connected to the same air cleaner, all the animals in the entire unit could be affected.

Annex F (informative): Examples of the contents of a user manual

Operation instructions include:

- The relevant parameters to be periodically controlled by the operator (daily/weekly, etc.).
- The adjustment of the parameters.
- The position and access to the relevant components of the installation.
- The operation during service times of the housing.
- The workflow for emptying, cleaning, and filling of the installation (e.g. change of water and exchange of the filter material).
- The documentation of the operation (e.g. data and maintenance work).

Service and maintenance instructions include:

- A maintenance schedule determining single and repetitive works and their rhythm, such as the calibration of the pH-meter, the cleaning of the system components, and the exchange of components (e.g. filter elements or material).
- The limit values of decisive parameters (e.g. pH-value, water filling height, and pressure drop) that cause certain maintenance work to be done.
- The position and access to the maintenance centres.
- Tools, protective devices, and auxiliary materials needed.

The largest part of the maintenance and repair work necessary can be carried out by the operator of the installation. In addition, a maintenance contract should be concluded with the manufacturer/applicant.

Instructions for preventing and dealing with incidents (environmental safety) include:

- Type of possible incidents (e.g. water spilling, power failure, and breakdown of ventilation), prevention, and measures to be taken.
- Waste management, i.e. production, amount, composition, and handling of wastes.
- Manufacturers/applicants hotline.

Note: In acid scrubbers and multi-stage systems, the ammonium sulphate solution must be regularly discharged from the chemical stage, and washing water contaminated with ammonium sulphate must be stored separately from the slurry in a special tank.

Surveillance instructions depending on the type of system operated include:

1. In general:

- The control of an even air flow through the contact bed packings and filter surfaces.
- The control of crude gas breakthroughs.
- The control of a sufficient and evenly moistening of the surfaces (regular checks of sprinkling density, the circulation pump, and the liquid distributor system, etc.); automatically controlled freshwater supply system with level control should be installed and checked regularly.

2. For biofilters:

- The control of the bed heights and the filter material properties, such as uniformity, grain size, age, and degree of decomposition of the material.
- The control and remove of emerging growth.

3. For trickling filters and single and multi-stage installations:

- The control for clogging and cleaning of wire-cloth drip separators and contact bed packings.
- The observation of the discharge rate.
- The checks of pH-control and acid metering systems.

Annex G (informative): Template for a test plan

NAME OF TEST BODY

TEST PLAN FOR [name of air cleaner]

[name of air cleaner] **integrated in ventilation system from** [name of manufacturer/applicant]

CONTACT DATA:

Herd owner/Chr. No.:	
Address of housing unit (if different from the address of the herd owner):	
Health status:	
Visiting rules:	
Start of test (dd/mm/yy):	
End of test (dd/mm/yy):	
Responsible technician:	
Technician(s):	
Consultant(s) from the test body:	
Local advisor/veterinarian:	
Contact person from the company financing the test:	
Service technician(s) from the air cleaning company and ventilation company:	
File:	

BACKGROUND AND AIM [maximum of one page]

A description of the air cleaning system, including the ventilation system, can be seen in Annex X. The development process of the air cleaner and any previous tests shall be specified (references shall be mentioned in the reference list at the end of the test plan).

This section shall include a precise description of the aim of the test and a specification of the primary test parameters.

TEST PROCEDURE

The description of the test procedure shall include the following items:

- Description of the herd, its management, and the air cleaning system where the test is conducted (previous description of the individual components in the air cleaner shall be specified in an appendix to the test plan. The verification authorities can then check that the applied air cleaning system is identical to the tested system).
- Specification of the primary measurement parameters, e.g. odour and ammonia: concentration before, in the middle, and after the air cleaner (see Table 3) and methods applied.
- Specification of the secondary measurement parameters and methods applied (see Table 6 of the VERA test protocol).
- Description of the location of measurement points, the sampling gas tubes, the instruments, and how they are calibrated in consideration of EN 15259:2007: *Air quality - Measurement of stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report.*
- Description of the work procedures in the housing unit and how the animal production parameters shall be recorded (see Table 6 of the VERA test protocol).
- Timetable for the entire test period.
- Logbook (location of logbook and description of parameters that shall be recorded).

DATA RECORDING

The tables to be used shall be stated.

ALLOCATION OF RESPONSIBILITY

The allocation of responsibility shall include all work processes, so the technician can use the list when instructing the stockmen. A list should be drawn up for each section and for each air cleaner.

What needs to be done	When	By whom

PROCESSING OF RESULTS

Raw data shall be presented in tables, which shall be included in appendices in the final test report. The raw data shall also be presented in graphs, which shall be included in the results section in the final test report.

The primary measurement parameters shall then be analysed in order to determine whether the concentration and emission after the air cleaner are statistically significantly different from the levels before the air cleaner.

For example, the ammonia concentration and the logarithmically transformed odour concentration can be processed with an analysis of variance in the MIXED Procedure in SAS (SAS Inst. Inc., Cary, NC). Both the medians and the 95^{th} percentiles shall be calculated for odour concentration, odour emission, and percentage differences before and after the air cleaner. For the other primary parameters, the average shall be calculated instead of the median.

The average and the standard deviation shall be calculated for the secondary parameters.

COMPENSATION

The herd owner is provided with compensation in connection with the test. The herd owner is paid DKK/Euro XXX per hour for any extra work.

APPENDICES

The appendices shall include all data recording tables, e.g. tables for:

- odour recordings;
- ammonia recordings;
- dunging behaviour; and
- production data.

UPDATINGS OF THE TEST PLAN

The test plan shall be updated every time changes are made. It is not enough to list the changes in the logbook. For each update, the date for the changes shall be noted, and the test plan shall be given a new version number.

Example:
1st version: DD/MM/YY initials 1/initials 2
2nd version: DD/MM/YY initials 1/initials 2

Annex H (informative): Example of a contract

CONTRACT

BETWEEN [name of the company financing the test]

AND [name of the test institute]

AND [name of the farmer(s)]

ABOUT Test of the air cleaner [name of air cleaner] delivered from [name of manufacturer/applicant]

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1 AIM

1.1 The aim is to test the air cleaner [name of air cleaner] according to the test protocol [name of test protocol].

2 SCOPE AND TEST PROCEDURE

2.1 The test includes the air cleaner and the connected ventilation system in a unit for sows/weaners/finishers weighing between xx and yy kg or poultry.

2.2 The enclosed test protocol states how the test shall be conducted and specifies which data recordings and analyses shall be performed.

2.3 The animals included in the trial shall be housed in accordance with EU and national legislation.

2.4 The herd owner, the company financing the test, and the manufacturer/applicant shall agree that all results will remain confidential during the test period and until the final test report is published.

2.5 Data recordings and analyses can be conducted by other institutes, providing this is specified in the contract.

2.6 The generation of data and the realisation of analyses shall be performed by accredited laboratories following ISO 17025. If analyses are carried out through other institutes, the accredited test body has the responsibility for the generated data.
The service contracts shall be drawn up before the test starts and shall not be changed during the test period.

3 REQUIREMENTS

3.1 Requirements for checking feed and production specified in the working plan shall be met by the herd owner.

3.2 All production-related data shall be available, including receipts for purchases and sales of animals and feed.

3.3. Animals shall only be moved in accordance with the guidelines laid down by the test body.

3.4 Changes to the housing unit and/or the production shall not be made without an agreement with the test body.

3.5. During the contract period, the herd owner shall not conduct tests with other parties other than the test body.

3.6. The herd owner shall agree to inform the herd veterinarian and production consultant that the test is being conducted.

4 HERD VISITS/INFORMATION/ANALYSIS

4.1 As required, a technician from the test body shall conduct an inspection of the herd and the air cleaning system. The technician shall collect data and provide the herd owner with data recording tables. Further details of the visits are described in the enclosed test protocol.

4.2. The results of the test shall remain confidential until the results have been published.

4.3. Analyses of the feed content shall be performed in accordance with the test plan.

5 TERMINATION OF THE CONTRACT

5.1 The contract runs until DD/MM/YY.

5.2 The contract is irrevocable for the farmer, the test body, and the manufacturer/applicant until DD/MM/YY.

5.3 In case of unforeseen problems with the animal production or air cleaner, the contract and test protocol can be reconsidered. If it is not possible to find a solution, the farmer, the test body, and/or the manufacturer/applicant may terminate the test with one month's notice.

6 VISITING RULES

6.1 When the herd owner signs the contract, he/she shall declare that the health status of the herd is ______________________. The test body shall be informed immediately of any disease outbreaks where the health status of the herd is at risk.

6.2 In order to disseminate the knowledge of the new technology, the herd owner shall agree to receive visits when contacted by the test body.

6.3 During herd visits, the herd owner shall agree to observe the general visiting rules, i.e. a quarantine period of at least 12 hours after contact with livestock with a lower health status than that of the herd owner's livestock. Quarantine is not required after visits on farms with livestock with a higher health status or the same health status.

If the herd owner has established his/her own visiting rules, these rules shall also be complied with.

7 COMPENSATION

Compensation is paid for extra work carried out during the test period. The herd owner is paid DKK/Euro XXX per hour for extra work.

This point shall include any agreements made by the three parties regarding the amount of compensation and what the compensation covers.

8 RESPONSIBILITY

8.1

8.2

9 RECONSTRUCTION COSTS

9.1 Costs relating to changes or installations that can be attributed to a specific test are covered by the test body or the manufacturer/applicant.

9.2 Equipment and material purchased by the test body or the manufacturer/applicant belong to these parties, unless otherwise agreed.

9.3 Ownership after completion of the test shall be specified.

9.4 If the herd owner terminates the present contract during the test period (see point 5.3), the test body and manufacturer/applicant reserve the right to decide what to do with the equipment installed on the farm. The herd owner can, by agreement with the test body, acquire the entire installation at a fixed price.

9.5 If the test body or the manufacturer/applicant terminate the present contract during the test period (see point 5.3), the ownership of the installation and equipment is as specified in point 9.3. Furthermore, if the manufacturer/applicant terminates the contract during the test period, they shall pay for the measurements taken so far.

9.6 If the herd owner goes bankrupt or the farm is put up for sale, the test body is entitled to reclaim the equipment purchased by the test body. The same applies to the manufacturer/applicant if the company goes bankrupt or closes down.

9.7 The herd owner is responsible for maintaining the equipment and covering the costs of fire insurance for the equipment installed in connection with the test. The herd owner is also responsible for ensuring that the equipment is in compliance with environmental approval.

9.8 With regard to test facilities established on the farm in connection with the test, the test body and the manufacturer/applicant are subject to the legislation of the country in which the test is performed. The test body is therefore not liable for any operating loss and cannot be held responsible for any indirect loss arising from the test facilities.

Date and place

Herd owner

Date and place

Applicant/Manufacturer

Date and place

Test institute