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Field testing of general ventilation filtration devices and systems for in situ removal efficiency by particle size and resistance to airflow

Essais in situ de filtres et systèmes de ventilation générale pour la mesure de l'efficacité en fonction de la taille des particules et de la résistance à l'écoulement de l'air

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 195, *Cleaning equipment for air and other gases,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 29462:2013), which has been technically revised.

The main changes are as follows:

— subclause 4.2 has been modified;

— some editorial corrections have been made.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to provide a test procedure for evaluating the in situ performances of general ventilation filtration devices and systems. Although any filter with a filtration efficiency at or above 99 % or at or below 30 % when measured at 0,4 µm can theoretically be tested using this document, it can be difficult to achieve statically acceptable results for these type of filtration devices.

Supply air to the heating, ventilation and air-conditioning (HVAC) system contains viable and non-viable particles of a broad size range. Over time these particles cause problems for fans, heat exchangers and other system parts, decreasing their function and increasing energy consumption and maintenance. For health issues, the fine particles (< 2,5 µm) are the most detrimental.

Particles in the 0,3 µm to 5,0 µm size range are typically measured by particle counters that can determine the concentration of particles in specific size ranges. These instruments are commercially available and determine particle size along with the concentration level by several techniques (e.g. light scattering, electrical mobility separation, or aerodynamic drag). Devices based on light scattering are currently the most convenient and commonly used instruments for this type of measurement and are therefore the type of device used within this document.

Particles in the size range 1,0 µm to 5,0 µm are present in low numbers (less than 1 %, by count) in outdoor and supply air and have higher sampling-system losses. Results in the range > 1,0 µm therefore have lower accuracy and should be interpreted accordingly.

During in situ measurement conditions, the optical properties of the particles can differ from the optical properties of the particles used for calibrating the particle counter and testing it in the laboratory. Thus the particle counter can size the particles differently but count the overall number of particles correctly.

By adding an extra reference filter, the effect of varying measuring conditions can be reduced. Additionally, using this enhanced test method, the results can be used to correct the measured efficiencies in relation to the efficiency of the reference filter measured in laboratory using a standardized test aerosol.

The results from using the standard method or the enhanced method give both users and manufacturers a better knowledge of actual filter and installation properties.

It is important to note that field measurements generally result in larger uncertainties in the results compared to laboratory measurements. Field measurements can produce uncertainty from temporal and spatial variability in particle concentrations, from limitations on sampling locations due to air handling unit configurations, and from the use of field instrumentation. These factors can result in lower accuracy and precision in the calculated fractional efficiencies compared to laboratory measurements. This document is intended to provide a practical method in which the accuracy and precision of the result are maximized (and the precision of the result quantified) by recommending appropriate sampling locations, sample quantities, and instrumentation. This document is not intended to serve as a filter performance rating method. The results obtained from the test method described in this document do not replace those obtained through tests conducted in the laboratory.

Field testing of general ventilation filtration devices and systems for in situ removal efficiency by particle size and resistance to airflow

1 Scope

This document describes a procedure for measuring the performance of general ventilation air cleaning devices in their end use installed configuration. The performance measurements include removal efficiency by particle size and the resistance to airflow. The test procedures include the definition and reporting of the system airflow.

The procedure describes a method of counting ambient air particles of 0,3 µm to 5,0 µm upstream and downstream of the in-place air cleaner(s) in a functioning air handling system. The procedure describes the reduction of particle counter data to calculate removal efficiency by particle size.

Since filter installations vary dramatically in design and shape, a protocol for evaluating the suitability of a site for filter evaluation and for system evaluation is included. When the evaluated site conditions meet the minimum criteria established for system evaluation, the performance evaluation of the system can also be performed according to this procedure.

This document also describes performance specifications for the testing equipment and defines procedures for calculating and reporting the results. This document is not intended for measuring performance of portable or movable room air cleaners or for evaluation of filter installations with an expected filtration efficiency at or above 99 % or at or below 30 % when measured at 0,4 µm.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
air filter bypass
proportion of the challenge air stream that passes around an air cleaner without interacting with the air cleaner (test device)

[SOURCE: ISO 29464:2017; 3.1.3, modified — The preferred terms "bypass" and "sneakage" have been deleted and "(test device)" has been added.]

3.1.2
air velocity
rate of air movement at the test device

Note 1 to entry: It is expressed in m/s (ft/min) to three significant figures.

[SOURCE: ISO 29464:2017, 3.1.2, modified — “at the test device” has been added to clarify the location, "fpm" has been changed to "ft/min".]

3.1.3
allowable measurable concentration of the particle counter
fifty percent of the maximum measurable concentration as stated by the manufacturer of the *particle counter* (3.1.12)

[SOURCE: ISO 29464:2017, 3.2.115]

3.1.4
coefficient of variation
C_V
standard deviation of a group of measurements divided by the mean

[SOURCE: ISO 29464:2017, 3.2.31]

3.1.5
coincidence error
error which occurs because at a given time more than one particle is contained in the measurement volume of a *particle counter* (3.1.12)

Note 1 to entry: The coincidence error leads to a measured number concentration which is too low and a value for the particle diameter which is too high.

[SOURCE: ISO 29464:2017, 3.2.32]

3.1.6
diluter
dilution system
system for reducing the sampled concentration to avoid *coincidence error* (3.1.5) in the *particle counter* (3.1.12)

[SOURCE: ISO 29464:2017, 3.2.46]

3.1.7
filter efficiency
fraction or percentage of a challenge contaminant that is removed by a test device

[SOURCE: ISO 29464:2017, 3.1.12, modified — The preferred term "efficiency" has been deleted.]

3.1.8
filter installation
filtration devices and systems such as a single filter or a group of filters mounted together with the same inlet and outlet of air

[SOURCE: ISO 29464:2017, 3.2.85]

3.1.9
general ventilation
process of moving air from outside the space, recirculated air, or a combination of these into or about a space or removing it from the space

[SOURCE: ISO 29464:2017, 3.2.100]

3.1.10
isoaxial sampling
sampling in which the flow in the sampler inlet is moving in the same direction as the flow being sampled

[SOURCE: ISO 29464:2017, 3.2.104]

3.1.11
isokinetic sampling
technique for air sampling such that the probe inlet *air velocity* (3.1.2) is the same as the velocity of the air surrounding the sampling point

[SOURCE: ISO 29464:2017, 3.2.105]

3.1.12
particle counter
device for detecting and counting numbers of discrete airborne particles present in a sample of air

[SOURCE: ISO 29464:2017, 3.2.114]

3.1.13
particle size range
defined *particle counter* (3.1.12) channel

[SOURCE: ISO 29464:2017, 3.2.137]

3.1.14
reference filter
dry media-type filter that has been laboratory tested for *removal efficiency by particle size* (3.1.15)

3.1.15
removal efficiency by particle size
removal efficiency
ratio of the number of particles retained by the filter to the number of particles measured upstream of the filter for a given particle-size range

[SOURCE: ISO 29464:2017, 3.2.149, modified — The preferred term "removal efficiency" has been added.]

3.1.16
resistance to airflow
difference in absolute (static) pressure between two points in a system

Note 1 to entry: Resistance to airflow is measured in Pa.

[SOURCE: ISO 29464:2017, 3.1.36, modified — The preferred terms "differential pressure", "pressure differential" and "pressure drop" have been deleted.]

3.1.17
system efficiency
removal efficiency (3.1.15) of a filter system where upstream and downstream particle count measurements may be across several filter banks or other system components

[SOURCE: ISO 29464:2017, 3.2.163]

3.1.18
HEPA filter
filters with performance complying with requirements of filter class ISO 35H to ISO 45H as per ISO 29463-1

[SOURCE: ISO 29464:2017, 3.2.84]

3.2 Abbreviated terms

AHU air handling unit

D/S downstream of test device

HVAC heating, ventilating and air-conditioning

OPC optical particle counter

RH relative humidity

U/S upstream of test device

VAV variable air volume

VFD variable frequency drive

4 Test equipment and setup

4.1 Particle counter

The particle counter should be capable of measuring particles in the size range 0,3 µm to 5,0 µm, in a minimum of four ranges with a minimum of two ranges below 1,0 µm (for example: 0,3 µm to 0,5 µm, 0,5 µm to 1,0 µm, 1,0 µm to 2,0 µm and 2,0 µm to 5,0 µm). For maintenance and calibration of the particle counter, see 4.9.

4.2 Diluter

A dilution system is required if the upstream aerosol concentration exceeds 50 % of the particle counter maximum concentration at 5 % coincidence error. The dilution system shall be capable of diluting the aerosol concentration so the particle concentration level is within the acceptable concentration limit. Choose a suitable dilution ratio so that the measured concentration of particles is within the limits of the allowable measurable concentration of the particle counter so as to achieve good statistical data (see 9.1.2). If a dilution system is used, it shall be used for both upstream and downstream sampling. The dilution system shall not change air flow to the particle counter.

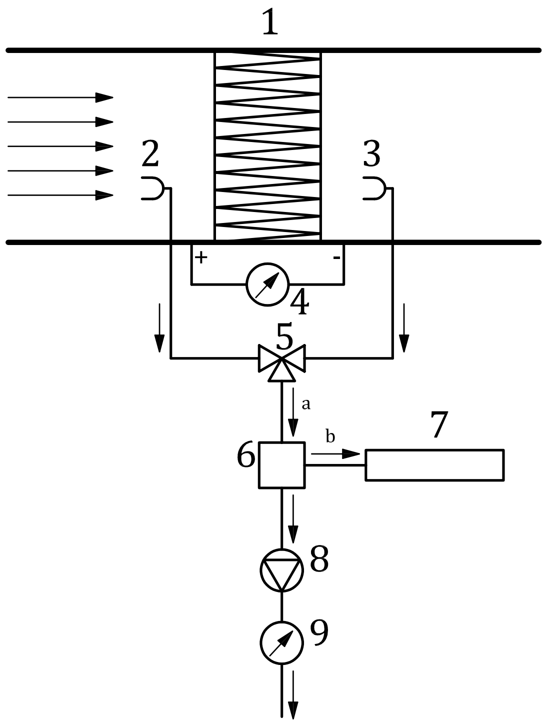
4.3 Pump

A pump may be used to control the rate of the sample flow (q_s) through the sampling probes. A pump is not necessary when the counter flow (q_{pc}) to the counter or diluter is sufficient for isokinetic sampling. In this case the sample flow (q_s) and the counter flow (q_{pc}) are the same.

4.4 Sampling system

4.4.1 General

Figure 1 shows the elements of a typical sampling system.



Key

1 test device
2 U/S probe
3 D/S probe
4 manometer
5 sample valve
6 isokinetic sampler
7 particle counter
8 pump
9 flow meter
a q_s – primary flow
b q_{pc} – flow to particle counter

Figure 1 — Sampling system

4.4.2 Sampling probes

The sampling probe should consist of a sharp-edged nozzle connected to the sample line leading to the auxiliary pump or particle counter. The diameter of the nozzle is dependent on the sample flow (q_s) in order to get isokinetic sampling. The diameter should not be less than 8 mm.

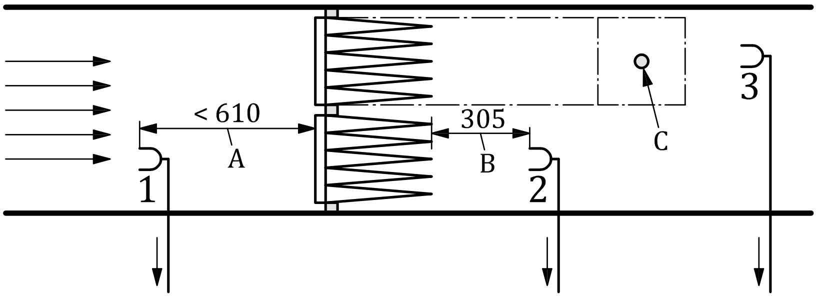
4.4.3 Sampling lines

Sampling lines upstream and downstream should be of equal length and as short as possible to avoid losses. Material should preferably be of a type with minimum particle losses for filter installations. Software is available to calculate line losses[2].

4.4.4 Sampling locations

Sampling locations should be placed close to the filter as shown in Figure 2. If the system efficiency is to be tested, the sampling locations should be further away to achieve good mixing of airflow through, e.g. filters, frames, doors. The measurement of the system efficiency is more difficult and therefore it is good practice to plan the measurement carefully and describe in detail how it was made.

Dimension in millimetres



Key

A minimum distance between the sampling probe and the filter

B distance between the end of the filter and the sampling probe

C location of sample points in y-z plane for filter efficiency tests

1 U/S sampling probe location

2 D/S sampling probe location for a filter efficiency test

3 D/S sampling probe location for a system efficiency test

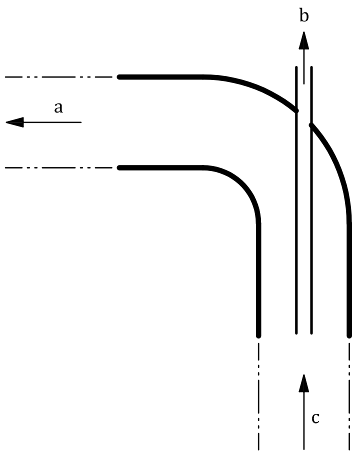
Figure 2 — Sampling locations

4.4.5 Valve (manual or automatic)

A valve may be used to switch between upstream and downstream sample locations. The valve should be constructed so that particle losses are identical in upstream and downstream measurements. No influence on efficiency due to the valve construction is permitted (for example, four-point ball valves of sufficient diameter can be used).

4.4.6 Isoaxial sampling nozzle

If a pump (see 4.3) is used to obtain isokinetic sampling, the sample line should then be fitted with an isoaxial sampling nozzle directly connected to the particle counter or diluter as shown in Figure 3.



Key

[a] Pump flow.

[b] q_{pc} – flow to particle counter.

[c] q_s – sample flow.

Figure 3 — Isoaxial sampling line to particle counter

4.4.7 Flow meter

A flow meter is necessary if a pump is part of the sampling system. The flow meter should be located in-line with the pump inlet or outlet.

4.5 Air velocity measurement instrument

The instrument used to measure the air velocity should have sufficient operational limits such that the system airflow is within the limits of the instrument. The instrument should be chosen in accordance with ISO 7726. An instrument that records data values and averages those values is recommended. Ideally, the instrument should have the ability to correct measurements to standard sea level atmospheric pressure conditions.

4.6 Relative humidity (RH) measurement instrument

The instrument used to measure the RH of the system airflow should have sufficient operational limits such that the system RH is within the limits of the instrument and should be chosen in accordance with ISO 7726. An instrument that records data values and averages those values over time is recommended.

4.7 Temperature measurement instrument

The instrument used to measure the temperature of the system airflow should have sufficient operational limits such that the system temperature is within the limits of the instrument and should be chosen in accordance with ISO 7726. An instrument that records data values and averages those values over time is recommended.

4.8 Resistance to airflow measurement instrument

The instrument used to measure the resistance of the filter bank should have sufficient operational limits such that the filter bank resistance is within the limits of the instrument, and should be chosen in accordance with ISO 14644-3. An instrument that records data values and averages those values over time is recommended.

4.9 Test equipment maintenance and calibration

Maintenance items and schedules should conform to Table 1.

Table 1 — Apparatus maintenance schedules

Maintenance item	Incorporated into each test	Annually	After a change that can alter performance
Particle counter zero check	X		
Sampling system zero check	X		
Resistance to airflow	X		
Air velocity	X		
Temperature, RH in sample air stream and at particle counter	X		
Upstream concentration test	X		
Reference filter test (field)	optional		
Reference filter test (lab)		X	X
Particle counter primary calibration		X	X

[a] Or as required by the equipment manufacturer.

Table 1 *(continued)*

Maintenance item	Incorporated into each test	Annually	After a change that can alter performance
Temperature, RH, air velocity, resistance to airflow equipment calibration		X [a]	X
Dilution system ratio check		X	X
Check sample probes for damage	X		
[a] Or as required by the equipment manufacturer.			

5 Site evaluation

5.1 General

This clause identifies the recommended minimum site conditions for performing a particle removal efficiency test.

5.2 Filter installation pre-testing inspection

Pre-inspection of filters and air handling units is necessary to determine whether a filter installation is suitable for evaluation using this document. It is also used to gauge whether any potentially hazardous conditions exist that would exclude or restrict access to the air handling unit.

Items provided in Annex A are some common items that may be reviewed during pre-testing inspection.

5.3 Approval for testing

Once the pre-testing inspection has been completed and the filter installation determined to be suitable for testing, then the “approval for testing form” should be completed and signed by representatives of the building owner or manager and the company performing the testing. A suitable form is shown in Annex B.

6 Test procedure

6.1 Air velocity

Air velocity through the filter installation should be maintained constant for the duration of the test. This is possible if the fan speed is controllable through variable frequency drive (VFD) or variable air volume (VAV) boxes and other modulating dampers are not allowed to adjust. In addition, the percentage of outside air in the supply air should also be kept constant to reduce fluctuations in particle count that would influence the test results.

The air velocity at the face of the filters should be measured using the instrument identified in 4.5. Air velocity measurements can be taken either upstream or downstream of the filters, but downstream is recommended. Since air velocity can vary significantly over the area of a filter installation, sampling points should be chosen such that measurements are taken at a minimum of 25 % of the filters and are distributed uniformly over the area of the filter installation. The measurement device should be extended away from turbulence caused by personnel or other obstructions. The velocity coefficient of variation (C_v) (see 9.3) should be less than 25 %.

Air velocity measurements should be conducted as close in time to resistance to airflow and removal efficiency testing as possible. This is to ensure that the system air velocity does not change significantly between the time of the velocity measurements and the time of the resistance to airflow and removal efficiency tests. Air velocity measurements shall be conducted both before and after the removal efficiency testing, with the velocity measurements averaged.

EXAMPLE

1st test: velocity measurement [average velocity = 2,0 m/s (394 ft/min)]

2nd test: resistance to airflow measurements

3rd test: removal efficiency testing

4th test: velocity measurements [average velocity = 2,2 m/s (433 ft/min)]

In this EXAMPLE, the reported average velocity would be 2,1 m/s (414 ft/min).

More frequent velocity measurements can be taken in systems exhibiting a high degree of variability in velocity over time.

6.2 Relative humidity (RH)

The instrument(s) identified in 4.6 should be used for these measurements. The RH of the air passing through the filter installation is recommended to be within the range of the particle counter and/or the RH measurement device used for the duration of the test. If system efficiency is being determined, the RH should be measured and recorded at the locations of the upstream and downstream probes. If measuring filter efficiency, the RH should be measured and recorded at one of the locations of the upstream or downstream probes. In addition, the RH should be recorded at the particle counter location. Wet-bulb temperature measurements referenced to the dry bulb temperature taken at the same time may be used in lieu of RH measurements.

6.3 Temperature

The instrument(s) identified in 4.7 should be used for this measurement. The temperature of the air passing through the filter installation should be within the operating range of the particle counting equipment. If system efficiency is being determined, the temperature (i.e. dry-bulb temperature) should be measured and recorded at the locations of the upstream and downstream probes. If measuring filter efficiency, the temperature should be measured and recorded at one of the locations of the upstream or downstream probes. In addition, the temperature should be recorded at the particle counter location. Care should be exercised if temperatures are extreme and/or outside of a normal equipment operating range. Particle counts should not be measured if temperatures are below freezing (see Clause 8).

6.4 Resistance to airflow

Resistance to airflow across the filter installation should be measured using the resistance to airflow instrument(s) identified in 4.8. If existing pressure reading equipment is installed, the resistance to airflow equipment may be connected to use the existing installed pressure probes. If existing probes are to be utilized, care shall be taken to ensure the existing probes are properly installed to read the static pressure and no component of velocity pressure. To read static pressure, the hole in the probe should be perpendicular to the flow with no obstructions prior to the probe so as to create a vortex. If air is being forced into the pressure probe, it reads velocity pressure instead of static pressure. Do not use existing probes if they appear to be bent, broken, clogged, non-functioning or not installed properly so they give an accurate reading of the resistance to airflow from the filters only. If the existing probes cannot be restored to an acceptable level of functioning prior to the testing, they should not be used.

Ideally, resistance to airflow measurements is recorded for each filter bank separately. However, in some cases the resistance value recorded is a combination of multiple filters in series as it can be physically impossible to measure separate resistance to airflow values.

It is good practice to measure at least 25 values for resistance to airflow over at least two total minutes and then average the measured values to determine the resistance to airflow. The C_v should be calculated and recorded for this data.

6.5 Removal efficiency

6.5.1 Removal efficiency tests

6.5.1.1 General

There are three types of tests described herein.

6.5.1.2 Filter efficiency

The purpose of this test is to determine the efficiency of the filter(s) for removing airborne particles. Downstream sampling locations should be chosen such that representative samples of air passing through the filters are obtained.

6.5.1.3 System efficiency

The purpose of this test is to determine the efficiency of the filtration system for removing airborne particles. The filtration system includes the filters and filter-holding frames. Downstream sampling locations and/or methods should be chosen such that representative samples of the total airflow passing through the filtration system are obtained. This includes air passing through the filters and around the filters (i.e. air filter bypass).

6.5.1.4 Other “system” tests

In addition to measuring filtration performance at the air filtration installation, this document can also be used to compare the concentration of airborne particles in different sections of an air handling unit and therefore test the air handling system as a whole.

NOTE In this document the results of other “system” tests are not referred to as “efficiencies” since the term “efficiency” implies that only particle-removal processes (and not particle addition) are involved. As the definition of the “system” gets larger due to the addition of other HVAC system components between the upstream and downstream locations, significant sources of particles (e.g. from leaks in the air handling unit housing) can affect the downstream particle concentrations.

EXAMPLE

Consider the following air handling unit:

1st component: prefilter installation

2nd component: cooling coil

3rd component: supply fan

4th component: final filter installation

In this EXAMPLE, samples can be taken upstream of the prefilter installation and downstream of the final filter installation to determine the difference in airborne particle concentrations across the four air handling unit components as a group. In this case, the “system” consists of all the components between the upstream and downstream sampling locations.

6.5.2 Sampling method

6.5.2.1 Particle counter instrument

Particle concentrations should be measured using the particle counter identified in 4.1. The same particle counter shall be used to measure both the upstream and downstream counts because matching of counters cannot be guaranteed if field particles are different from the laboratory particles used for calibration.

6.5.2.2 Sample volume

Samples for all tests (including the zero test) shall be drawn for the time required to sample 1,0 l (0.035 ft^3) of air or 20 s, whichever time is longer. The recommended sample volume is expected to provide sufficient particle counts for statistically acceptable results according to Clause 9. For a removal efficiency value to be calculated, the average upstream concentration for the discrete particle size should be a minimum of 37 counts per litre (1 048 counts per cubic foot).

In some systems, the minimum sample volume required does not yield statistically acceptable counts for all particle sizes. In this case, a longer sampling time can be used to improve the statistical validity of the measurement. It is not always possible to achieve statistically acceptable results in all particle size ranges.

The sample volume and sample time shall not be changed at any time once particle counting for efficiency has been started. If a change to sampling volume or sample time is necessary to improve statistical validity, the test shall be restarted so that all samples are measured using the same sample volume and sample time.

6.5.2.3 Purge sampling lines

Purging should be carried out once at the start of each upstream dataset and each downstream dataset. The purge time shall be at least five times the calculated time required for a particle to travel from the sample probe to the particle counter.

6.5.2.4 Particle counter zero test

Before efficiency testing, the zero count at the particle counter should be checked by connecting a HEPA filter directly to the particle counter and measuring for a minimum of one-minute count. The sum of the concentration of particles in all size ranges shall be less than 10 counts per litre (280 counts per cubic foot).

6.5.2.5 Concentration limit

After verifying the particle counter zero test, it should be established that upstream and downstream aerosol concentrations are within the range of the measuring equipment (particle counter, diluter) and high enough to produce reasonable statistical accuracy for the results (as determined in Clause 9). Concentration sampling can be measured according to 6.5.2.9. Undiluted samples shall not be taken at concentrations above the allowable measurable concentration of the particle counter. The diluter identified in 4.2 should be used to carry out the test if upstream particle counts are above this level. The actual concentration is then calculated from the measured concentration and the dilution ratio.

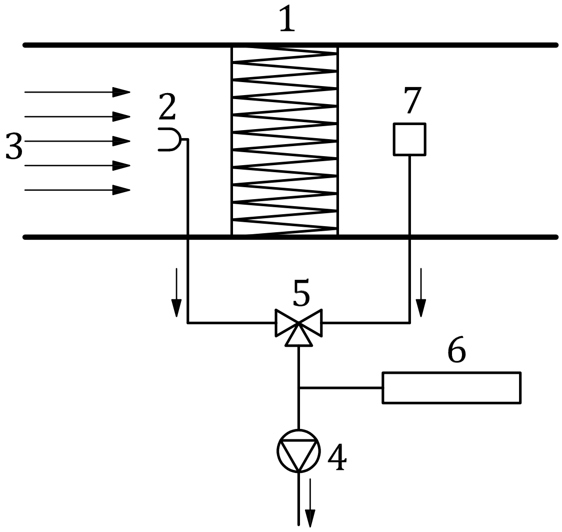
In addition to the maximum concentration limit, each particle size channel should have a minimum average concentration as described in 9.1.2.

6.5.2.6 System zero test

After verifying the concentration limit, the system zero count should be checked by connecting a HEPA filter at the downstream probe location as shown in Figure 4. Take a minimum of a one-minute particle count through the HEPA filter and downstream sample lines. The allowable maximum concentration of particles in all size ranges is the greater of 0,05 % of the upstream concentration or 10 counts per litre (280 counts per cubic foot). An example is shown below.

EXAMPLE

Measured concentration =	35 300 counts per litre (1 000 000 counts per cubic foot)
Maximum leak rate =	0,05 %
Allowable concentration =	18 counts per litre (500 counts per cubic foot)



Key

1 test device
2 U/S probe
3 airflow
4 pump
5 valve
6 particle counter
7 HEPA filter at downstream

Figure 4 — Checking zero count at downstream sampling line

6.5.2.7 Isokinetic sampling

Sampling errors can occur when the collection air velocity (i.e. in the sampling probe) is different from the free-stream air velocity (i.e. in the air handling unit). To minimize these errors, ensure that the sampling probe(s) is (are) aligned directly (parallel) into the air stream and that the collection air velocity is matched to the free-stream air velocity. The collection air velocity can be adjusted by changing the diameter and/or number of sampling probes or by changing the sampling flow rate (see Figure 1). A supplemental pump may be used if needed. Isoaxial sampling to the particle counter is acceptable (see Figure 3).

EXAMPLE Assume a measured air velocity of 1,65 m/s (325 ft/min) and a probe diameter of 13 mm (0.51 inches).

$$q_c = V * \frac{d^2 * \pi}{4} * C_{si}$$

where

q_c is the calculated sample flow, m^3/s (ft^3/min);

V is the measured air velocity, m/s (ft/min);

d is the diameter of the sample probe, mm (inch);

C_{si} is the unit conversion value, $1,0 \times e^{-6}$ ($6,94 \times e^{-3}$).

In this EXAMPLE, the calculated sample flow is 2,19 x 10^{-4} m^3/s (0.46 ft^3/min). The collection air flow should be set as close as possible to the calculated sample flow value ±20 %.

NOTE Isokinetic sampling has long been deemed necessary to promote the collection of representative samples of particles in air. For isokinetic sampling, the velocity in the sampling tube or port is matched with the velocity in the main gas stream. If the velocity in the sample tube is lower, then errors due to sampling occur since only a fraction of the air stream in the projected flow area is sampled. Furthermore, if the differential is too large and the main flow velocities large, some of the dynamic head can increase the static head inside the tube, leading to further errors. If the sampling velocity is too high, the sample is greater than the projected flow area. Sampling flows within 20 % of the main flow rate can reduce sampling errors. This range has been found to be a good balance between the flow variations one encounters in the field and the need for isokinetic sampling. In addition, using sample probes with aerodynamic entrance cross-sections and without large flat surfaces can prevent impaction losses, particularly of larger particles.

6.5.2.8 Sampling system setup

All sample points should be connected to one sampling tube leading to the particle counter. A valve can be mounted so it is easy to switch between upstream and downstream sample lines. All sampling tubes, valves, and bends should be chosen to minimize particle concentration level changes from that encountered within the air stream. It is permissible to use a portable particle counter if it meets the requirements of 4.1, and the particle counter is positioned in a manner such that a representative sample of the air stream is obtained. A stand (e.g. tripod) should be used to hold the particle counter. Personnel shall not be present in the air handling unit during sampling to avoid sampling errors associated with the disturbance of airflow patterns and sampling of particles released from the operator's body. See 6.1 for more information.

6.5.2.9 Pre-screening of particle concentrations

The variability in the particle concentrations both in space (i.e. different concentrations at different locations over the area of the filter installation) and time (i.e. changing concentrations over time) should be assessed to determine the most appropriate probe location for conducting the test. To achieve this, it is recommended that each of the following samples be taken at the upstream location prior to initiating the removal efficiency sampling:

— at least five samples should be taken at one location to assess variability with time;

— at least five samples should be taken at different locations over the face of a large filter installation to assess variability over space. For small filter installations, fewer locations may be used.

A high degree of variability in these data can result in lower precision in the calculated fractional efficiencies. As a result, if the C_v (9.3) of either set of measurements is greater than 25 % (unless the average count for any particle size channel is less than 50 particles, in which case for those channels the C_v limit is 50 %) for any particle size channel, then one of the following two actions should be taken. Either more than the minimum number of datasets listed in 6.5.2.10 should be taken, or the sampling should be rejected. If for any particle size channel there is a concentration below the limit shown in 9.1.2 no removal efficiency should be calculated.

6.5.2.10 Dataset

Each dataset shall consist of a minimum of six individual particle samples for each probe location. A particle sample consists of particle count data for each of the size ranges associated with the particle counter. Additional particle samples are recommended and can lead to lower uncertainty values as calculated in Clause 9.

6.5.2.11 Number of datasets

Multiple sample datasets shall be taken to address variability in particle concentrations both in space (i.e. different concentrations at different locations over the area of the filter installation) and time (i.e. changing concentrations over time). A minimum of four downstream datasets and three upstream datasets shall be collected. Datasets shall be collected alternately downstream and upstream, starting with the downstream sample. For example, if seven datasets are taken, they shall be taken in the following order: downstream, upstream, downstream, upstream, downstream, upstream, and downstream. Additional datasets are recommended and can lead to lower uncertainty values as calculated in Clause 9.

6.6 Sampling probes

6.6.1 Location of sampling probes

The location of the particle sampling probes should be chosen from locations with consistent and stable velocity readings. The measured velocity at the sample location should have a coefficient of variation (C_v < 25 %).

6.6.2 Location of upstream sampling probes

Upstream sampling probes should be positioned so that a representative sample of the upstream concentration is obtained. The inlet of the probe upstream of the filter should be located within 610 mm (24 inches) upstream of the filter surface as shown in Figure 2.

6.6.3 Location of downstream sampling probes — Filter efficiency test

For filter efficiency tests, the inlet of the probe downstream of the filter should be located 305 mm (12 inches) downstream of the filter and at the centre of the filter as shown in Figure 2. If it is not physically possible to position the sample probe 305 mm (12 inches) downstream of the filters (e.g. if the coils are positioned within 305 mm (12 inches) of the filters), then it is permissible to locate the probe less than 305 mm (12 inches) from the filters, but not within the volume of the filter (e.g. between pleats, pockets, or in the filter media).

6.6.4 Location of downstream sampling probes — System efficiency test

For the system efficiency tests, the inlet of the probe downstream of the filter should be located as far downstream as possible, but before the next major HVAC system component that can remove particles from the air stream. For example, if the filter installation is followed by cooling coils, the downstream sampling probe should be located immediately in front of the coils. Samples should be taken in a manner such that a representative sample of the total airflow passing through the filtration system is obtained. This includes air both passing through the filters and around the filters (i.e. air filter bypass). This can require the use of a sample manifold having multiple sampling probes. Alternatively, multiple samples from different single locations over the face of the filter installation can be taken. These sampling locations should be uniformly distributed in space and cover the entire area of the filter installation. Sequential upstream-downstream samples should be taken at similar locations relative to the face of the filter installation.

7 Expression of results

7.1 General information

A complete report shall include all the information in the “filter installation pre-testing inspection form” and the “approval for testing form” (see Table A.1 and Table B.1). A sample of a completed test report is shown in Annex C with the completed forms shown in Table C.1 and Table C.2. The following information shall also be included in a complete report:

a) owner information:

— name, address, phone, e-mail;

— building;

   — AHU;
   — system description;

b) test/AHU information:
   — test date and time;
   — filter installation date;
   — location of test device(s) in bank;
   — schematic drawing of the installation showing sample points for resistance to airflow and particle sampling;
   — whether diluter was used;
   — probe locations: distance from test device (mm or inch):
      — upstream;
      — downstream;
   — whether a downstream sample manifold having multiple sampling probes was used (if applicable a description/drawing/photo)
   — air supply (% outdoor, indoor or mix);
   — operation description (daily usage);
   — filter face area in the system (per bank), m^2 (ft^2);
   — other remarks (abnormal or unusual conditions, which can influence the results);

c) filter description:
   — filter model(s)/description(s);
   — part number(s)/identification number(s);
   — test filter serial number (if not available, show N/A)
   — filter size(s) and quantity for each size;
   — media type (fiberglass, charged synthetic);
   — media colour(s);
   — estimated filter media area, m^2 (ft^2);

d) equipment:
   — particle counter:
      — manufacturer and model number;
      — calibration date;
      — flow rate, m^3/s (ft^3/min);
      — particle size ranges;

  - — particle concentration corresponding to 5 % coincidence error;
- — temperature measuring device:
  - — manufacturer and model number;
  - — calibration date;
- — RH measuring device:
  - — manufacturer and model number;
  - — calibration date;
- — resistance to airflow measuring device:
  - — manufacturer and model number;
  - — calibration date;
- — air velocity measuring device:
  - — manufacturer and model number;
  - — calibration date.

7.2 Data collection

The data reported shall include the following:

1) zero count data;

2) pre-screening of concentration;

3) air velocity:

   i) the average air velocity value(s) for the filter installation; if measurements are taken before and after particle readings, values should be reported for before, after and average;

   ii) the C_v for each of the air velocity data sets shall be reported;

4) temperature:

   i) the temperature of the air within the system shall be reported;

   ii) the temperature of the air around the particle counter shall be reported;

5) RH:

   i) the RH of the air within the system shall be reported;

   ii) the RH of the air around the particle counter shall be reported;

6) resistance to airflow:

   i) the average resistance to airflow value(s) for the filter installation; if measurements are taken before and after particle readings, values should be reported for before, after and average;

   ii) the C_v for each of the resistance to airflow data sets shall be reported;

7) removal efficiency:

   i) the average removal efficiency shall be reported by particle size for each particle size channel within the range 0,3 µm to 5,0 µm available from the particle counter;

ii) the upper and lower uncertainty values shall be calculated and reported for each particle size channel within the range 0,3 µm to 5,0 µm available from the particle counter;

iii) the C_v values shall be calculated and reported for each particle size channel within the range 0,3 µm to 5,0 µm available from the particle counter;

iv) the values shall be calculated as shown in Clause 9;

8) raw data:

i) tables showing a summary of the data samples should be included in the final report;

ii) the raw count data showing date, time, sample time, and raw counts for each size range should be available if requested.

8 Errors and data analyses

8.1 General

Attention to the possible sources of errors ensures that the measurements are as close to error-free as possible. This clause addresses the common causes of errors, but is not intended as an exhaustive treatment of the subject. Furthermore, with field measurements, many of the conditions noted below that can lead to errors cannot be controlled (i.e. one takes what one gets). Use of replicate measurements and verification of system stability at least ensures that any systematic errors in the measurements are minimized.

8.2 Relative humidity (RH)

High RH, typically above 80 %, can cause variations in efficiency and can increase the resistance to airflow. High RH increases the size of hygroscopic particles. Particles can dry before reaching the detection chamber in the particle counter and have a different size from that at the air filter. The humidity can also change the refractive index of the particles and influence the measured size. The enhanced test method described in Clause 10 can be used to correct the result.

8.3 Air temperature

Operating conditions at or below freezing lead to freezing of permanently installed sampling probes and lines, and to errors in particle counter operation if these conditions are outside the normal operating range, as well as condensation and freezing of moisture on surfaces. Unless performance of the system is requested to be evaluated for these conditions, it is preferable to avoid taking measurements at these temperatures.

8.4 Aerosol composition

Since optical particle counters are the instrument of choice for many professionals in the field, the measured particle size is dependent on the refractive index and shape of the particles. However, one has little control over the properties of particles in the field. In general, as an overall precaution, measurements should be avoided when the air stream appears to be laden with dark or deeply pigmented particles such as soot or visible smoke.

8.5 Uniformity of aerosol concentration

The particle concentration in an installation typically varies with time and space. Such variations can lead to errors in the data. To minimize such errors, the system evaluation procedures discussed in Clause 5 and Clause 6 shall be followed. The variability in measured concentrations with respect to time and space should be reported with the results.

8.6 Coincidence errors — Particle counter

Coincidence errors in particle counters occur when two particles enter the viewing volume of the counter and their coincident signals are counted as one larger signal or particle. This is more common at higher concentrations. Instrument manufacturers generally provide data on the concentrations and coincidence errors for their instrument. In general, particle concentrations in excess of 50 % of the maximum concentration at 5 % coincidence error shall be avoided. At these concentrations, a diluter is required (see 4.2) to reduce the measured concentration to within acceptable limits. As per ISO 21501-1, the maximum concentration of the particle counter should be known. Note that when a diluter is used, the calibration of the diluter to each particle size is required for estimating the actual (undiluted) particle concentration. Nominal dilution ratios are not acceptable.

8.7 Particle losses

Particle losses can occur in sampling lines in dilution systems, if used, and in instruments themselves. The losses are typically significant for larger particles due to impaction on surfaces, while very small particles minimize losses on surfaces due to diffusion. In practice, losses are not expected to affect results in the field significantly for particles between 0,3 µm to 1,0 µm.

Errors due to particle losses can be minimized by duplicating the sample train for upstream and downstream sampling. The sampling train includes sample probes, tube lengths, and flow configuration to the instrument(s). Minimizing sample tube lengths and the use of metallic or non-charge-retaining material sample tubes reduce diffusion losses. Loss of larger particles can be minimized by avoiding sharp changes in flow directions, by using ball valves instead of needle valves, and by ensuring that there are smooth changes to flow cross-sections. Lastly, isokinetic sampling as discussed in 6.5.2.7 should be used to minimize sample losses at the point of collection.

A quick estimate of particle losses in any section of the measurement system can be easily obtained by measuring the particle concentrations before and after the device or section of the sample train in question. One can use the same particle counter used for the field measurement and use the particles in ambient air to estimate the losses. If the loss in any part of the sample train exceeds 5 % or the aggregate loss in all the components exceeds 10 %, it can be necessary to reconfigure the sample train or apply correction factors to the results. Software is available to calculate line losses[2].

9 Calculation of results

9.1 Calculation of removal efficiency

9.1.1 General

Each dataset consists of multiple samples. Datasets are taken sequentially beginning and ending with a downstream dataset and alternating between downstream and upstream as shown in Table 2.

Table 2 — Sampling cycle example

Sequence number	1	2	3	4	5	6	7	8	9	10	11	12	13
Downstream	D_1		D_2		D_3		D_4		D_5		D_6		D_7
Upstream		U_1		U_2		U_3		U_4		U_5		U_6	

9.1.2 Dataset sample average

In each dataset, there is an average of the sample data for each particle size range, calculated as follows:

$$\overline{U}_{d,c} = \frac{\sum_{i=1}^{n} U_{d,c,i}}{n}$$

$$\overline{D}_{d,c} = \frac{\sum_{i=1}^{n} D_{d,c,i}}{n}$$

where

$\overline{D}_{d,c}$	is the average downstream count for dataset D_d for each of the particle size ranges;
$\overline{U}_{d,c}$	is the average upstream count for dataset U_d for each of the particle size ranges;
$D_{d,c,i}$	is the downstream count for dataset d and particle size range c;
$U_{d,c,i}$	is the upstream count for dataset d and particle size range c;
d	is the dataset number (either upstream or downstream);
c	is the number of particle size ranges;
n	is the number of samples per dataset.

9.1.3 Minimum upstream concentration

In order to calculate an efficiency value, the average of the upstream particles measured at the particle counter for any particle size range should be greater than or equal to 37 counts per litre (1 048 counts per cubic foot). If the upstream concentration does not meet this minimum requirement, the removal efficiency for that particle size range in that dataset shall be reported as "N/A". The use of a diluter to reduce the upstream concentration to a level the particle counter can handle, can cause several of the larger particle size ranges to not meet this minimum criterion.

Upstream concentration average:

$$\overline{U}_{d,\mathrm{con}} = \frac{\overline{U}_{d,c}}{t_\mathrm{s} \times q_2}$$

where

$\overline{U}_{d,\mathrm{con}}$	is the average upstream concentration for dataset *d;*
t_s	is the sample time of particle counter in min;
q_2	is the particle counter flow rate in litres per min (cubic ft/min);

$\overline{U}_{d,\mathrm{con}} \geq 37$ counts per litre

or

$\overline{U}_{d,\mathrm{con}} \geq 1\,048$ counts per cubic foot.

9.1.4 Particle size range efficiency

For each particle size range, there is an efficiency calculated for each upstream dataset as follows:

$$E_{d,c} = \left[1 - \frac{\left(\dfrac{\overline{D}_{d,c} + \overline{D}_{d+1,c}}{2} \right)}{\overline{U}_{d,c}} \right] \times 100$$

where

$E_{\mathrm{d,c}}$ is the removal efficiency by particle size range for each upstream dataset;

d is the dataset number of upstream dataset.

9.1.5 Average efficiency by particle size

The efficiency values are then averaged to determine the removal efficiency by particle size as follows:

$$\overline{E}_c = \frac{\sum_{i=1}^{d} E_{c,i}}{N}$$

where

$\overline{E}_c$ is the average of the removal efficiency by particle size range for each upstream dataset value;

N is the number of upstream samples.

9.2 Calculation of uncertainty

9.2.1 General

The uncertainty on the average removal efficiency as defined in 9.1.4 corresponds to a two-sided confidence interval of the average value based on a 95 % confidence level. Uncertainty values should also be calculated for the resistance to airflow and the air velocity datasets. This statistical calculation addresses the variability of this measurement but it is possible that it does not address the variations due to field and environmental changes.

9.2.2 95 % confidence limit

The 95 % confidence limit of the removal efficiency can be determined by:

$$\overline{E}_{\mathrm{lcl},c} = \overline{E}_c - \delta \times \frac{t}{\sqrt{n}}$$

and

$$\overline{E}_{\mathrm{ucl},c} = \overline{E}_c + \delta \times \frac{t}{\sqrt{n}}$$

$$\delta_c = \sqrt{\frac{\sum_{i=1}^{n} \left(E_{c,i} - \overline{E}_c \right)^2}{n-1}}$$

where

$\overline{E}_{\mathrm{lcl},c}$	is the lower confidence limit;
$\overline{E}_{\mathrm{ucl},c}$	is the upper confidence limit;
δ_c	is the standard deviation of the efficiency values for the particle size range;
t	is the t distribution variable from Table 3;
n	is the number of values;
c	is the number of particle size ranges.

9.3 Coefficient of variation (C_{v})

The coefficient of variation (C_{v}) is the standard deviation of a group of measurements divided by the mean. The C_{v} shows the extent of variability of data in a sample in relation to the mean of the population. A C_{v} value below 25 % is generally acceptable for most measured values, except where noted.

$$C_{\mathrm{v}} = \frac{\delta_c}{E_c}$$

Table 3 — Distribution variable

Number of samples	**Degrees of freedom** $v = n - 1$	t
3	2	4,303
4	3	3,182
5	4	2,776
6	5	2,571
7	6	2,447
8	7	2,365
9	8	2,306
10	9	2,262
11	10	2,228
12	11	2,201
13	12	2,179
14	13	2,160
15	14	2,145
16	15	2,131
17	16	2,120
18	17	2,110
19	18	2,101
20	19	2,093
21	20	2,086
22	21	2,080
23	22	2,074
24	23	2,069
25	24	2,064
26	25	2,060

Table 3 *(continued)*

Number of samples	Degrees of freedom $v = n - 1$	t
27	26	2,056
28	27	2,052
29	28	2,048
30	29	2,045
inf.	inf.	1,960

10 Optional enhanced test system

10.1 Application of enhanced test system

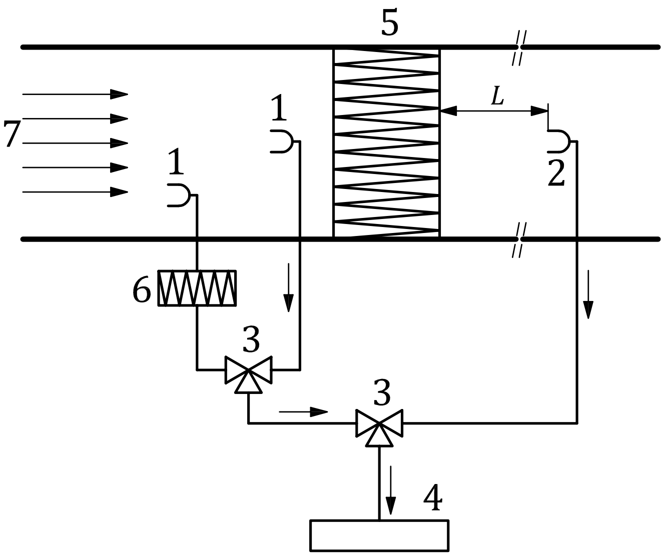
The purpose of the optional enhanced test system is to offer a method of correlation between standard laboratory test data and in situ test data. By challenging a filter that has been previously tested under laboratory conditions with the same ambient aerosol in situ, a correlation of the data can be established. This method should be used only where the measured air velocity and particle concentrations are stable, i.e. $C_v < 25$ %. The correction of particle sizing can be done only where the particle concentration for that size is statistically stable, i.e. $C_v < 10$ %.

Another method of obtaining a laboratory correlation is to remove a sample filter from the AHU after the in situ testing is complete and send the removed filter to an independent testing laboratory that can complete an efficiency test by particle size. The laboratory should be instructed to test the used filter without loading dust or conditioning the filter and at the average flow rate measured in the field. Comparison of removal efficiency data to the laboratory test data of like particle size also gives a laboratory correlation.

10.2 Principle of the enhanced test system

Using the enhanced test system illustrated in Figure 5, it is possible to measure almost simultaneously the efficiency of the filter installation and a reference filter of equivalent efficiency. The effects of varying measurement conditions can thus be reduced. Additionally, the results can be used to correct the measured efficiencies in relation to the efficiency of the reference filter measured in the laboratory using a standardized test aerosol. In order to avoid additional errors, the same optical particle counter should be used both in the laboratory and with the in situ measurements. The reference filter should preferably be of the same type and efficiency level as the filter to be in situ tested.

The enhanced test system includes three sampling lines so that there is an additional sampling line and valve for the reference filter upstream of the test device. The aerosol sampling system is used to measure particle concentrations alternatively from upstream and downstream of the test device and reference filter. The timing of the measurement is shown in Table 4. The removal efficiency results are calculated both for the reference filter and the test device using the procedures presented in Clause 9.



Key

1 U/S probe
2 D/S probe
3 valves
4 particle counter
5 test device
6 reference filter
7 air flow
L distance from test device to downstream test location

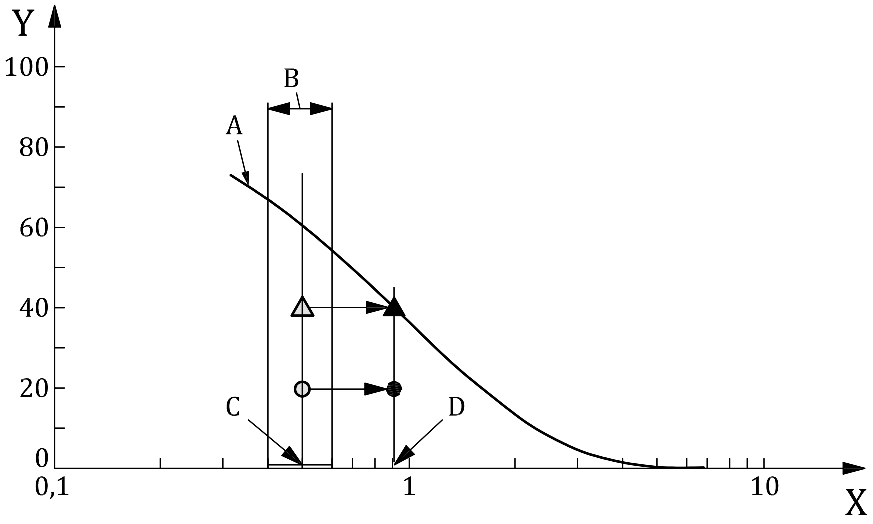
Figure 5 — Schematic of the enhanced test system

Table 4 — Sampling cycles in the enhanced test system

Sequence number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Downstream	D_1			D_2			D_3			D_4			D_5			D_6			D_7
Upstream		U_1			U_2			U_3			U_4			U_5			U_6		
Reference			R_1			R_2			R_3			R_4			R_5			R_6	

10.3 Determination of the corrected particle size

An optical particle counter sizes the particles based on their optical properties. During in situ measurement conditions, the optical properties of the particles can differ from the optical properties of the particles used when calibrating the particle counter and when conducting laboratory tests. Thus the particle counter sizes the particles differently but still counts the number of the particles correctly. The resulting efficiency/penetration curve has comparable efficiency values at different particle sizes compared to the laboratory results. The particle sizes can be corrected by comparison to the laboratory efficiency/penetration curve of the reference filter. This procedure is illustrated in Figure 6 for a single particle size.



Key

X particle size, µm

Y penetration, %

A reference filter, laboratory calibration curve (penetration)

B OPC's size channel

C OPC channel geometric mean

D corrected particle size

△ reference filter, measured field test result at the OPC channel geometric mean

○ test device, measured field test result at the OPC channel geometric mean

▲ reference filter, result of size correction

● test device, result of size correction

Figure 6 — Determination of the corrected particle size

The penetration of the reference filter measured with in situ particles (the reference filter, measured field test result) at the OPC channel geometric mean is compared to the reference filter laboratory calibration curve in order to find the corrected particle size. The corrected particle size for a reference filter measured field test result is the particle size that has an equal penetration on the reference filter laboratory calibration curve. This particle size correction is also made for the test device data. The procedure is then repeated for all measured particle sizes with statistically valid data.

10.4 Presentation of results

When the enhanced test system is used, the test report should present, in addition to what is stated in Clause 7, the following data:

— efficiency of the reference filter measured in laboratory;

— efficiency of the reference filter measured using ambient particles;

— efficiency of the test device measured using ambient particles;

— efficiency of the test device measured using ambient particles and the corrected particle sizes.

Annex A
(informative)

Filter installation pre-testing inspection form

Table A.1 — Filter installation pre-testing inspection form

	Air handling unit description	Yes	No	Note #
a.	Adequate overall air tightness?			
b.	Doors have adequate seals (very little air leakage)?			
c.	Doors available on both sides of air filter banks?			
d.	Doors have provision for opening/closure from inside AHU?			
e.	Adequate space (U/S and D/S) of filter banks for probe placement and measurement?			
f.	Adequate space (up/down stream) of other equipment (i.e. coils, fan) for instrument placement and measurement?			
g.	Is a multiple probe manifold needed for downstream measurement? (see 6.6.4)			
h.	Sample ports located and labelled (up/downstream) of filter banks?			
i.	Adequate overall interior cleanliness?			
j.	Adequate overall exterior access to AHU?			
k.	Any hazardous conditions (i.e. slip, head knockers, standing water, chemical)?			
l.	Adequate guards provided on the fans and motors?			
m.	Can the filter airflow be set to a constant value for the duration of the test?			
	Local instrumentation description	**Yes**	**No**	**Note #**
a.	Are differential pressure gauges working properly and calibrated?			
b.	Are pressure taps properly aligned? (i.e. not bent, broken or clogged)			
c.	Is there a velocity gauge working properly and calibrated?			
d.	Is there a temperature gauge working properly and calibrated?			
e.	Is there a relative humidity gauge working properly and calibrated?			
	Filters/Frames description	**Yes**	**No**	**Note #**
a.	Bank #1 - Proper seating/sealing of filters?			
b.	Bank #1 - Clamping hardware in place?			
c.	Bank #1 - Filters free from damage?			
d.	Bank #2 - Proper seating/sealing of filters?			
e.	Bank #2 - Clamping hardware in place?			
f.	Bank #2 - Filters free from damage?			
g.	Bank #3 - Proper seating/sealing of filters?			
h.	Bank #3 - Clamping hardware in place?			
i.	Bank #3 - Filters free from damage?			
	Utilities description	**Yes**	**No**	**Note #**
a.	Available electric outlet for instrument power?			
b.	Adequate working internal lighting?			

Note #	Notes description

Table A.1 *(continued)*

Annex B
(informative)

Approval for testing form

This approval of the customer and the testing firm (contractor) allows for the gathering of filter installation data to provide both parties with an understanding of the actual system performance resulting in an acceptable future filtration configuration and performance.

Table B.1 — Approval for testing form

<table>
<tr><td colspan="3">Customer:</td></tr>
<tr><td colspan="3">Address:</td></tr>
<tr><td colspan="3">Contractor:</td></tr>
<tr><td colspan="3">Address:</td></tr>
<tr><td colspan="3">Number of air handling units:</td></tr>
<tr><td colspan="3">Environmental parameters to be measured: (resistance to airflow, air velocity, temperature and relative humidity)</td></tr>
<tr><td colspan="3">Filter installation testing protocol: ISO 29462</td></tr>
<tr><td colspan="3">Comments:</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3" align="center">Acceptance (check one box)</td></tr>
<tr><td>With comments:</td><td>Without comments</td><td>Not accepted</td></tr>
<tr><td colspan="3">Customer representative:</td></tr>
<tr><td colspan="2">Signature:</td><td>Date:</td></tr>
<tr><td colspan="3">Contractor representative:</td></tr>
<tr><td colspan="2">Signature:</td><td>Date:</td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="3" align="center">Air handling units to be tested</td></tr>
<tr><td>Item #</td><td>Building ID</td><td>AHU ID</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
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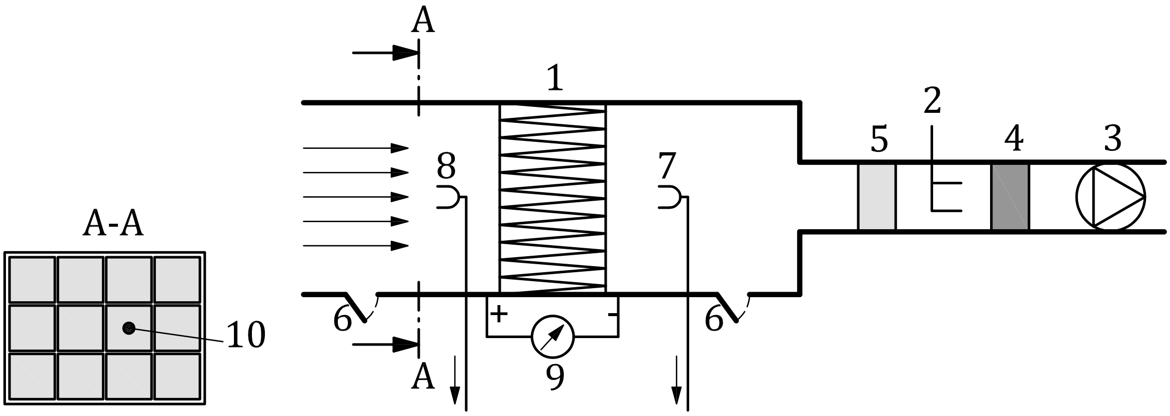
<tr><td></td><td></td><td></td></tr>
</table>

Annex C
(informative)

Example of how to complete testing

C.1 General

A filter installation, as shown in Figure C.1, consisting of twelve nominal full-size filters (610 mm × 610 mm) (24 inches × 24 inches) in a bank are tested. The test procedure should be conducted according to Clause 6.



Key

1	filter installation	7	D/S sample probe
2	humidifier	8	U/S sample probe
3	fan	9	manometer
4	cooling coil	10	sample point location
5	heating coil	A-A	cross-section A-A of filter
6	door		

Figure C.1 — Schematic drawing of the installation

C.2 Preliminary forms

C.2.1 General

A completed “filter installation pre-testing inspection form” is attached with notes. Also, a completed “approval for testing form” is attached. These forms are provided in Annexes A and B.

C.2.2 Filter installation pre-testing inspection form

Table C.1 — Completed sample of filter installation pre-testing inspection form

	Air handling unit description	Yes	No	Note #
a.	Adequate overall air tightness?	X		
b.	Doors have adequate seals (very little air leakage)?	X		
c.	Doors available on both sides of air filter banks?	X		

Table C.1 *(continued)*

d.	Doors have provision for opening/closure from inside AHU?	X		
e.	Adequate space (U/S and D/S) of filter banks for probe placement and measurement?	X		
f.	Adequate space (up/downstream) of other equipment (i.e. coils, fan) for instrument placement and measurement?	X		
g.	Does the system require a multiple probe manifold for downstream measurement? (see 6.6.4)		X	
h.	Sample ports located and labelled (up/downstream) of filter banks?	X		1
i.	Adequate overall interior cleanliness?	X		
j.	Adequate overall exterior access to AHU?	X		
k.	Any hazardous conditions (i.e. slip, head knockers, standing water, chemical)?		X	
l.	Adequate guards provided on the fans and motors?	X		
m.	Can the airflow through the filters be set to a constant value for the duration of the test?	X		
	Local instrumentation description	**Yes**	**No**	**Note #**
a.	Are differential pressure gauges working properly and calibrated?		X	3
b.	Are pressure taps properly aligned, i.e. not bent, broken or clogged?			N/A
c.	Is there a velocity gauge working properly and calibrated?		X	2
d.	Is there a temperature gauge working properly and calibrated?		X	4
e.	Is there a relative humidity gauge working properly and calibrated?		X	4
	Filter/Frames description	**Yes**	**No**	**Note #**
a.	Bank #1 - Proper seating/sealing of filters?		X	5
b.	Bank #1 - Clamping hardware in place?		X	6
c.	Bank #1 - Filters free from damage?	X		
d.	Bank #2 - Proper seating/sealing of filters?			N/A
e.	Bank #2 - Clamping hardware in place?			N/A
f.	Bank #2 - Filters free from damage?			N/A
g.	Bank #3 - Proper seating/sealing of filters?			N/A
h.	Bank #3 - Clamping hardware in place?			N/A
i.	Bank #3 - Filters free from damage?			N/A
	Utilities description	**Yes**	**No**	**Note #**
a.	Available electric outlet for instrument power?	X		
b.	Adequate working internal lighting?	X		

Note #	Notes description
1	Holes drilled for the particle sampling lines.
2	VFDs are locked to deliver approximately at 2,03 m/s (400 ft/min) for testing
3	Installed gauges read 0-6 225 Pa (0-25 inch WG). Not able to read filter resistance. Should be replaced with a 0-500 Pa (0-2 inch WG) gauge.
4	Not installed.
5	Filters missing gaskets. Gaskets replaced prior to starting test.
6	Some spring fasteners missing. Replaced prior to starting testing.

C.2.3 Approval for testing form

Table C.2 — Completed sample of approval for testing form

<table>
<tr><td colspan="4">Customer: Someone's company, Inc.</td></tr>
<tr><td colspan="4">Address: 1313 Mockingbird Lane, Some City, Some State, 12345</td></tr>
<tr><td colspan="4">Contractor: Walrus Testing</td></tr>
<tr><td colspan="4">Address: 909 Blue Jay Way, Some City, Some State, 12345</td></tr>
<tr><td colspan="4">Number of air handling units: 2</td></tr>
<tr><td colspan="4">Environmental parameters to be measured: (resistance to airflow, air velocity, temperature and relative humidity)</td></tr>
<tr><td colspan="4">Filter installation testing protocol: ISO 29462</td></tr>
<tr><td colspan="4">Comments: We will be testing 2 different AHUs during each site visit. We will be on site a total of 3 visits approximately 6-8 weeks apart. The first test will be when filters are newly installed.</td></tr>
<tr><td colspan="4" align="center">Acceptance (check one box)</td></tr>
<tr><td colspan="2">With comments: X</td><td>Without comments:</td><td>Not accepted</td></tr>
<tr><td colspan="4">Customer representative: John Q. Customer</td></tr>
<tr><td colspan="3">Signature: John Q. Customer</td><td>Date: 27 Feb 2021</td></tr>
<tr><td colspan="4">Contractor representative: Seymour Filter</td></tr>
<tr><td colspan="2">Signature: Seymour Filter</td><td colspan="2">Date: 27 Feb 2021</td></tr>
<tr><td colspan="4" align="center">Air handling units to be tested</td></tr>
<tr><td>Item #</td><td>Building ID</td><td colspan="2">AHU ID</td></tr>
<tr><td>1</td><td>12-North Mech Room</td><td colspan="2">AHU 12-01</td></tr>
<tr><td>2</td><td>12-North Mech Room</td><td colspan="2">AHU 12-02</td></tr>
</table>

C.3 Qualification testing

C.3.1 General

The sampling points are located so the influence of turbulence (e.g. from door, walls) is held to a minimum. The resistance to airflow is measured across the filter and the taps are located to be as close to the filters as achievable to eliminate reading static pressure from other than the filters. RH and temperature are measured on the upstream side close to filter installation and outside the duct where the particle counter is located. Air flow is measured by taking a velocity profile across the entire filter bank. The test device is selected as the closest filter to the door with a velocity measurement close to the average across the duct.

Tables C.3 to C.27 show the data results for this example. The particle counter flow rate for all samples is 0,047 l/s (0.1 ft^3/min).

C.3.2 Velocity data

Velocity readings are taken on the downstream side of each filter maintaining the probe approximately 200 mm to 300 mm (8 inches to 12 inches) from each filter. Care is taken to not allow turbulence from personnel influencing the values.

Table C.3 — Velocity data

Velocity data set #1 (before any testing)

Location	Velocity data m/s (ft/min)
R1-C1	1,65 (324)
R1-C2	2,07 (407)
R1-C3	1,86 (366)
R1-C4	1,91 (376)
R2-C1	2,25 (443)
R2-C2	2,32 (456)
R2-C3	2,04 (402)[a]
R2-C4	2,13 (420)
R3-C1	2,09 (412)
R3-C2	2,14 (421)
R3-C3	1,95 (384)
R3-C4	2,03 (399)
Average	**2,04 (401)**
C_v	**8,8 %**

[a] Select position R2-C3 for particle testing.

Velocity data set #2 (after testing)

Location	Velocity data m/s (ft/min)
R1-C1	1,68 (331)
R1-C2	2,09 (411)
R1-C3	1,83 (361)
R1-C4	1,96 (385)
R2-C1	2,29 (451)
R2-C2	2,28 (448)
R2-C3	2,05 (403)
R2-C4	2,11 (416)
R3-C1	2,09 (411)
R3-C2	2,12 (417)
R3-C3	1,99 (392)
R3-C4	2,07 (407)
Average	**2,05 (403)**
C_v	**8,3 %**

	C1	C2	C3	C4
R1				
R2				
R3				

Since the reported average velocity = 2,04 m/s (402 ft/min) and the average C_v = 8,5 %, then the average velocity is within the acceptable range.

C.3.3 Isokinetic sampling

Calculate the sample flow (q_c) based on the measured average velocity. Sample probe diameter is 13 mm (0.51 inches) as shown in Formula (C.1).

$$q_c = \frac{(13)^2 \pi}{4} \times \frac{1}{1 \times 10^6} \times 2{,}04 \text{ or } q_c = \frac{(0.51)^2 \pi}{4} \times \frac{1}{144} \times 402 \tag{C.1}$$

NOTE For all testing, 2,7 × 10^{-4} m/s (0,57 cfm) is used for q_s.

C.3.4 Temperature and relative humidity (RH)

Temperature and RH are measured by placing the probe into the air flow and collecting sufficient data points to record the average temperature and RH.

These data are the average of 25 readings:

Table C.4 — Temperature and RH data

Location	Temperature °C (°F)	Temperature limits[a] °C (°F)	RH %	RH limits[a] %
In-duct	20,1 (68.2)	1 to 38 (33 to 100)	55	10 to 80
Particle counter	22,3 (72.1)		58	

[a] From measuring equipment specifications.

Conclusion: Based upon the averages of the 25 readings, the temperature and humidity are within acceptable ranges.

C.3.5 Resistance to airflow data

Resistance to airflow can be measured while the removal efficiency data is being measured. Since the installed gauge cannot be accurately read (0 Pa to 10 Pa, 0 inch to 25 inches WG), the contractor shall use his or her instrumentation to measure resistance to airflow.

Based upon the average of 25 readings, the resistance to airflow = 84,6 Pa (0.34 inches WG) for Cv = 3,0.

C.3.6 Particle counter zero test

Install a HEPA filter to the particle counter air inlet for a minimum of a one-minute count measurement. If the calculated concentration is lower than the maximum, the test passes.

Data show the total counts for a one-minute sample.

Table C.5 — Particle counter zero data

Cumulative counts (all channels)	**Calculated concentration** counts per litre (counts per cubic foot)	**Maximum concentration** counts per litre (counts per cubic foot)
7	2,5 (70)	10 (280)

The results show that the zero test is within an acceptable range.

C.3.7 Upstream particle concentrations

C.3.7.1 Pre-screening of particle concentration in space

Using the particle counter and the upstream probe, sample the particle concentration at five locations in the duct. The selected locations are R1-C2, R1-C4, R2-C1, R2-C3 and R3-C2 from the diagram shown in C.3.2. Acquire a minimum of one sample of 20 s at each location and determine the average particle count and the C_v for the data set. The maximum C_v allowable is 25 % unless the average count for any particle size channel is less than 50 particles. For those channels, the C_v limit is 50 %.

Table C.6 — Particle concentration in space data

Size range (µm)	**Differential data** Particles (20 s samples, 1 location)					**Average particles**	**Standard deviation**	C_v %	**Maximum** C_v %	**Pass or fail**
	R1-C2	R1-C4	R2-C1	R2-C3	R3-C2					
0,3 to 0,5	19 851	16 333	19 724	18 793	16 812	18 303	1 640,1	9,0	25	Pass
0,5 to 0,7	9 123	7 683	8 732	7 981	8 222	8 339	592,1	7,1		Pass
0,7 to 1,0	1 456	1 186	1 379	1 313	1 096	1 286	145,2	11,3		Pass
1,0 to 2,0	623	434	564	411	368	480	108,3	22,6		Pass
2,0 to 5,0	31	18	27	25	16	23	6,3	26,8	50	Pass
> 5,0[a]	8	4	6	4	3	5	2,0	40,0		Pass
Total	**31 092**	**25 613**	**30 432**	**28 527**	**26 517**	**28 436**				

[a] Extra data.

Conclusion: The C_v for all six channels is within an acceptable range.

C.3.7.2 Pre-screening of particle concentration in time

Using the particle counter and the upstream probe, sample the particle concentration at the location selected from C.3.2. Sample a minimum of 5 counts of 20 s each and determine the average concentration and the C_v for the data set. The maximum C_v allowable is 25 %.

Table C.7 — Particle concentration in time data

Size range (µm)	Differential data Particles (20 s samples, 1 location)					Average particles	Standard deviation	C_v %	Maximum C_v %	Pass or fail
	1	2	3	4	5					
0,3 to 0,5	18 143	17 880	18 967	20 461	19 488	18 988	1 044,3	5,5	25	Pass
0,5 to 0,7	8 432	7 987	8 321	8 765	8 028	8 307	318,5	3,8		Pass
0,7 to 1,0	1 100	985	1 322	1 213	966	1 117	151,5	13,6		Pass
1,0 to 2,0	527	489	543	518	477	511	27,2	5,3		Pass
2,0 to 5,0	35	32	41	37	32	27	9,1	33,2	50	Pass
> 5,0[a]	5	7	6	8	4	6	1,6	26,4		Pass
Total	**28 236**	**27 367**	**29 194**	**31 002**	**28 980**	**28 956**				

[a] Extra data.

Conclusion: The C_v for all six channels is within an acceptable range.

C.3.7.3 Minimum upstream concentration

Using the particle size channel data from C.3.7.2, average particle counts for each size are converted into concentrations and compared to the minimum value for reporting efficiency data.

The minimum upstream concentration data is shown in Table C.8.

Table C.8 — Minimum upstream concentration data

Size range (µm)	Average (particles)	Particle concentration counts per litre (counts per cubic foot)	Minimum particle concentration counts per litre (counts per cubic foot)	Pass or fail
0,3 to 0,5	18 988	20 200 (569 634)	37 (1 048)	Pass
0,5 to 0,7	8 307	8 837 (249 198)		Pass
0,7 to 1,0	1 117	1 189 (33 516)		Pass
1,0 to 2,0	511	543 (15 324)		Pass
2,0 to 5,0	27	29 (822)		Fail
> 5,0[a]	6	6 (180)		Fail
Total	**28 956**			

[a] Extra data.

Conclusion: The concentrations are within the acceptable range for the first four size ranges in Table C.8 and no diluter is required. But efficiency should not be reported for the 2,0 µm to 5,0 µm or 5,0 µm to 20 µm size ranges.

C.3.7.4 Particle concentration limit

Use the cumulative data from C.3.7.2 from the minimum of 5 counts of 20 s each and determine the average concentration and the C_v for the data set.

The maximum upstream concentration data is shown in Table C.9.

Table C.9 — Maximum upstream concentration data

Count number	**Cumulative data** Particles (20 s)	**Upstream concentration** counts per cubic metre (counts per cubic foot)	**Max. concentration**[a] counts per cubic metre (counts per cubic foot)
1	28 236	23 987 (847 080)	35 300 (1 000 000)
2	27 367	29 114 (821 010)	
3	29 194	31 057 (875 820)	
4	31 002	32 981 (930 060)	
5	28 980	30 830 (869 400)	
Average	**28 956**	**30 804 (868 674)**	

[a] Defined as 50 % of the max. concentration as stated by the particle counter manufacturer.

Conclusion: The average concentration is within the acceptable range and no diluter is required.

C.3.8 System zero test

Install a HEPA filter at the downstream probe location air inlet for a minimum of a one-minute count measurement. If the measured particle concentration is less than 0,05 % of the upstream concentration from C.3.7, then the test passes.

Data show the total counts for a one-minute sample.

Table C.10 — System zero test data

Cumulative counts (all channels)	**Measured concentration** counts per litre (counts per cubic foot)	**Upstream concentration** counts per litre (counts per cubic foot)	**Allowable concentration** counts per litre (counts per cubic foot)
12	4,3 (120)	30 804 (868 674)	15 (434)

Conclusion: Since the measured particle concentration is less than 0,05 % of the upstream concentration, the system zero test is within the acceptable range.

C.4 Filter efficiency data

C.4.1 General

A minimum of four datasets are collected on the downstream side of one filter location and three datasets on the upstream side of the same filter location. Each dataset consists of six particle samples of 20 s each. Each particle sample provides particle count data for each particle size channel.

C.4.2 Downstream data

The downstream probe is located 305 mm (12 inches) from the back of the test device at the centre of the filter.

Table C.11 — Filter efficiency – downstream data

Size range (µm)	Downstream dataset 1 (particles)						Average particles
	1	2	3	4	5	6	
0,3 to 0,5	5 004	5 124	4 873	6 023	5 290	5 348	5 277
0,5 to 0,7	1 702	1 721	1 647	1 818	1 857	1 750	1 749
0,7 to 1,0	155	142	138	165	176	161	156
1,0 to 2,0	42	43	32	38	35	28	36
2,0 to 5,0	1	0	1	2	0	1	1
> 5,0[a]	0	0	1	1	0	0	0
Total	**6 904**	**7 030**	**6 692**	**8 047**	**7 358**	**7 288**	**7 220**

[a] Extra data.

C.4.3 Upstream data

The upstream probe is located 450 mm (18 inches) from the face of the test device at the centre of the filter.

Table C.12 — Filter efficiency – upstream data

Size range (µm)	Upstream dataset 1 (particles)						Average particles
	1	2	3	4	5	6	
0,3 to 0,5	19 472	19 813	17 709	19 874	19 038	17 175	18 847
0,5 to 0,7	8 653	8 843	7 789	8 727	8 011	7 943	8 328
0,7 to 1,0	1 267	1 198	954	1 231	1 032	1 001	1 114
1,0 to 2,0	612	585	510	564	417	377	511
2,0 to 5,0	34	31	21	30	25	18	27
> 5,0[a]	8	8	4	6	4	3	6
Total	**30 046**	**30 478**	**26 987**	**30 432**	**28 527**	**26 517**	**28 831**

[a] Extra data.

C.4.4 Particle count data

The data sets are collected by alternating between downstream and upstream until all datasets are collected. The average particle counts for each particle size channel are shown.

Table C.13 — Filter efficiency - all count data

Size range (µm)	Average dataset values (differential particles)							Average upstream (particles)	Average downstream (particles)
	D_1	U_1	D_2	U_2	D_3	U_3	D_4		
0,3 to 0,5	—	18 847	—	18 756	—	17 980	—	18 528	—
	5 277	—	5 428	—	5 127	—	5 102	—	5 234
0,5 to 0,7	—	8 328	—	8 398	—	8 178	—	8 301	—
	1 749	—	1 827	—	1 701	—	1 698	—	1 744
0,7 to 1,0	—	1 114	—	1 201	—	1 056	—	1 124	—
	156	—	171	—	151	—	146	—	156

[a] Extra data.

Table C.13 *(continued)*

Size range (µm)	Average dataset values (differential particles)							Average upstream (particles)	Average downstream (particles)
	D_1	U_1	D_2	U_2	D_3	U_3	D_4		
1,0 to 2,0	—	511	—	499	—	453	—	488	—
	36	—	41	—	31	—	28	—	34
2,0 to 5,0	—	27	—	26	—	18	—	24	—
	1	—	2	—	1	—	0	—	1
> 5,0[a]	—	6	—	7	—	3	—	5	—
	0	—	1	—	0	—	0	—	0
Total	**7 219**	**28 833**	**7 470**	**28 887**	**7 011**	**27 688**	**6 974**		

[a] Extra data.

C.4.5 Filter efficiency calculation

Table C.14 — Filter efficiency - calculation data

Size range (µm)	Efficiency calculations %			Average efficiency %	Standard deviation	95 % upper confidence limit %	95 % lower confidence limit %	C_v %
	Eff 1	Eff 2	Eff 3					
0,3 to 0,5	71,6	71,9	71,6	71,7	0,001 7	72,1	71,3	0,2
0,5 to 0,7	78,5	79,0	79,2	78,9	0,003 5	79,8	78,0	0,4
0,7 to 1,0	85,3	86,6	85,9	86,0	0,006 4	87,5	84,4	0,7
1,0 to 2,0	92,5	92,8	93,5	92,9	0,005 2	94,2	91,6	0,6
2,0 to 5,0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
> 5,0[a]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[a] Extra data.

Efficiency values should not be reported for the channels that do not meet the data requirements.

C.5 Sample report

ISO 29462 test report

Owner:

John Q. Customer

Someone's company, Inc.

1313 rue Mockingbird

Some city, some state, 12345

(111) 222-3333

jqc@SomeoneCo.com

Testing firm:

Seymour filter

Walrus Testing

909 Blue Jay Way

Some city, some state, 12345

(111) 444-5555

filtergeek@WalrusTest.com

System description: This AHU has 12 full size filters operating at approximately 2,03 m/s (400 ft/min) with 100 % outdoor air in a 24/7 continuous operation. There is approximately 4,46 m^2 (48 ft^2) of filter face area in the system. The details of the installation can be found in the filter inspection form attached.

Table C.15 — Sample report – filter information

Filter	Manufacturer	Model	Part number	Qty	Size, mm (inch)	Media type	Media colour	Estimated media area
PreFilter	FilterGeeks	Pleat8	FilGeek-1	12	305×305×50 (24×24×2)	Charged Synthetic	White	1,36 m^2 (15 ft^2)
Final	FilterGeeks	S-Bag	Fil-GeekB-85-22-8	12	305×305×560 (24×24×22) 8p	Charged Synthetic	Pink	4,65 m^2 (50 ft^2)

Test date and time: 27 Feb 2021 09:00am

Filter installation date: 27 Feb 2021

Attachment 1 – Schematic of system to be tested (see Figure C.1 for sample)

Attachment 2 – Filter installation pre-testing inspection form (see C.2.1 for sample)

Attachment 3 – Approval for testing form (see C.2.2 for sample)

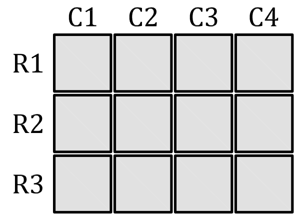
Table C.16 — Sample report – velocity data

Velocity data set #1
(before any testing)

Location	**Velocity data** m/s (ft/min)
R1-C1	1,68 (331)
R1-C2	2,09 (411)
R1-C3	1,83 (361)
R1-C4	1,96 (385)
R2-C1	2,29 (451)
R2-C2	2,28 (448)
R2-C3	2,05 (403)
R2-C4	2,11 (416)
R3-C1	2,09 (411)
R3-C2	2,12 (417)
R3-C3	1,99 (392)
R3-C4	2,07 (407)
Average	**2,05 (403)**
C_v	**8,8 %**

Velocity data set #2
(after testing)

Location	**Velocity data** m/s (ft/min)
R1-C1	1,65 (324)
R1-C2	2,07 (407)
R1-C3	1,86 (366)
R1-C4	1,91 (376)
R2-C1	2,25 (443)
R2-C2	2,32 (456)
R2-C3	2,04 (402)[a]
R2-C4	2,13 (420)
R3-C1	2,09 (412)
R3-C2	2,14 (421)
R3-C3	1,95 (384)
R3-C4	2,03 (399)
Average	**2,04 (401)**
C_v	**8,3 %**



[a] Select position R2-C3 for particle testing.

Conclusion: Since the reported average velocity = 2,04 m/s (402 ft/min) and the average C_v = 8,5 %, then the average velocity is within the acceptable range.

Table C.17 — Sample report – temperature and RH data

Location	**Temp** °C (°F)	**Temp limits**[a] °C (°F)	**RH** %	**RH limits**[a] %
In-duct	20,1 (68.2)	1 to 38 (33 to 100)	55	10 to 80
Particle counter	22,3 (72.1)		58	

[a] From measuring equipment specifications.

Conclusion: The temperature and humidity are within acceptable ranges.

Conclusion: Based upon the average of 25 readings, the resistance to airflow = 84,6 Pa (0.34 inches WG) for C_v = 3,0.

Table C.18 — Sample report – particle counter zero test data

Cumulative counts (all channels)	**Calculated concentration** counts per litre (counts per cubic foot)	**Maximum concentration** counts per litre (counts per cubic foot)
7	2,5 (70)	10 (280)

Data show the total counts for a one-minute sample.

Conclusion: The results show that the zero test is within an acceptable range.

Table C.19 — Sample report – particle concentration in space data

Size range (µm)	Differential data Particles (20 s samples, 1 location)					Average particles	Standard deviation	C_v %	Maximum C_v %	Pass or fail
	R1-C2	R1-C4	R2-C1	R2-C3	R3-C2					
0,3 to 0,5	19 851	16 333	19 724	18 793	16 812	18 303	1 640,1	9,0	25	Pass
0,5 to 0,7	9 123	7 683	8 732	7 981	8 222	8 339	592,1	7,1		Pass
0,7 to 1,0	1 456	1 186	1 379	1 313	1 096	1 286	145,2	11,3		Pass
1,0 to 2,0	623	434	564	411	368	480	108,3	22,6		Pass
2,0 to 5,0	31	18	27	25	16	23	6,3	26,8	50	Pass
> 5,0[a]	8	4	6	4	3	5	2,0	40,0		Pass
Total	**31 092**	**25 613**	**30 432**	**28 527**	**26 517**	**28 436**				

[a] Extra data.

Conclusion: The C_v for all six channels is within an acceptable range.

Table C.20 — Sample report – particle concentration in time data

Size range (µm)	Differential data Particles (20 s samples, 1 location)					Average particles	Standard deviation	C_v %	Maximum C_v %	Pass or fail
	1	2	3	4	5					
0,3 to 0,5	18 143	17 880	18 967	20 461	19 488	18 988	1 044,3	5,5	25	Pass
0,5 to 0,7	8 432	7 987	8 321	8 765	8 028	8 307	318,5	3,8		Pass
0,7 to 1,0	1 100	985	1 322	1 213	966	1 117	151,5	13,6		Pass
1,0 to 2,0	527	489	543	518	477	511	27,2	5,3		Pass
2,0 to 5,0	35	32	41	37	32	27	9,1	33,2	50	Pass
> 5,0[a]	5	7	6	8	4	6	1,6	26,4		Pass
Total	**28 236**	**27 367**	**29 194**	**31 002**	**28 980**	**28 956**				

[a] Extra data.

Conclusion: The C_v for all six channels is within an acceptable range.

Table C.21 — Sample report – minimum concentration

Size range (µm)	**Average** (Particles)	**Particle concentration** counts per litre (counts per cubic foot)	**Minimum particle** concentration counts per litre (counts per cubic foot)	**Pass or fail**
0,3 to 0,5	18 988	20 200 (569 634)	37 (1 048)[b]	Pass
0,5 to 0,7	8 307	8 837 (249 198)		Pass
0,7 to 1,0	1 117	1 189 (33 516)		Pass
1,0 to 2,0	511	543 (15 324)		Pass
2,0 to 5,0	37	29 (822)		Fail
> 5,0[a]	6	6 (180)		Fail
Total	**28 956**			

[a] Extra data.

[b] Defined as 50 % of the max. concentration as stated by the particle counter manufacturer.

Conclusion: The concentrations are within the acceptable range for the first four size ranges in Table C.21 and no diluter is required. But efficiency should not be reported for the 2,0 µm — 5,0 µm or 5,0 µm — 20 µm size ranges.

Table C.22 — Sample report – maximum concentration data

Count number	**Cumulative data** Particles (20 s)	**Upstream concentration** counts per cubic metre (counts per cubic foot)	**Max. concentration**[a] counts per cubic metre (counts per cubic foot)
1	28 236	23 987 (847 080)	35 300 (1 000 000)
2	27 367	29 114 (821 010)	
3	29 194	31 057 (875 820)	
4	31 002	32 981 (930 060)	
5	28 980	30 830 (869 400)	
Average	**28 956**	**30 804 (868 674)**	

[a] Defined as 50 % of the max. concentration as stated by the particle counter manufacturer.

Conclusion: The average concentration is within the acceptable range and no diluter is required.

Table C.23 — Sample report – system zero test data

Cumulative counts (all channels)	**Measured concentration** counts per litre (counts per cubic foot)	**Upstream concentration** counts per litre (counts per cubic foot)	**Allowable concentration** counts per litre (counts per cubic foot)
12	4,3 (120)	30 804 (868 674)	15 (434)

Data show the total counts for a one-minute sample.

Conclusion: Since the measured particle concentration is less than 0,05 % of the upstream concentration, the system zero test is within the acceptable range.

Table C.24 — Sample report – filter efficiency downstream data

Size range (µm)	**Downstream dataset 1** (particles)						**Average particles**
	1	2	3	4	5	6	
0,3 to 0,5	5 004	5 124	4 873	6 023	5 290	5 348	5 277
0,5 to 0,7	1 702	1 721	1 647	1 818	1 857	1 750	1 749
0,7 to 1,0	155	142	138	165	176	161	156
1,0 to 2,0	42	43	32	38	35	28	36
2,0 to 5,0	1	0	1	2	0	1	1
> 5,0[a]	0	0	1	1	0	0	0
Total	**6 904**	**7 030**	**6 692**	**8 047**	**7 358**	**7 288**	**7 220**

[a] Extra data.

Table C.25 — Sample report – filter efficiency upstream data

Size range (µm)	Upstream dataset 1 (particles)						Average particles
	1	2	3	4	5	6	
0,3 to 0,5	19 472	19 813	17 709	19 874	19 038	17 175	18 847
0,5 to 0,7	8 653	8 843	7 789	8 727	8 011	7 943	8 328
0,7 to 1,0	1 267	1 198	954	1 231	1 032	1 001	1 114
1,0 to 2,0	612	585	510	564	417	377	511
2,0 to 5,0	34	31	21	30	25	18	27
> 5,0[a]	8	8	4	6	4	3	6
Total	**30 046**	**30 478**	**26 987**	**30 432**	**28 527**	**26 517**	**28 831**

[a] Extra data.

Table C.26 — Sample report – particle count data

Size range (µm)	Average dataset values (differential particles)							Average upstream (particles)	Average downstream (particles)
	D_1	U_1	D_2	U_2	D_3	U_3	D_4		
0,3 to 0,5	—	18 847	—	18 756	—	17 980	—	18 528	—
	5 277	—	5 428	—	5 127	—	5 102	—	5 234
0,5 to 0,7	—	8 328	—	8 398	—	8 178	—	8 301	—
	1 749	—	1 827	—	1 701	—	1 698	—	1 744
0,7 to 1,0	—	1 114	—	1 201	—	1 056	—	1 124	—
	156	—	171	—	151	—	146	—	156
1,0 to 2,0	—	511	—	499	—	453	—	488	—
	36	—	41	—	31	—	28	—	34
2,0 to 5,0	—	27	—	26	—	18	—	24	—
	1	—	2	—	1	—	0	—	1
> 5,0[a]	—	6	—	7	—	3	—	5	—
	0	—	1	—	0	—	0	—	0
Total	**7 219**	**28 833**	**7 470**	**28 887**	**7 011**	**27 688**	**6 974**		

[a] Extra data.

Table C.27 — Sample report – filter efficiency calculations

Size range (µm)	Efficiency calculations %			Average efficiency %	Standard deviation	95% upper confidence limit %	95% lower confidence limit %	C_v %
	Eff 1	Eff 2	Eff 3					
0,3 to 0,5	71,6	71,9	71,6	71,7	0,0 017	72,1	71,3	0,2
0,5 to 0,7	78,5	79,0	79,2	78,9	0,0 035	79,8	78,0	0,4
0,7 to 1,0	85,3	86,6	85,9	86,0	0,0 064	87,5	84,4	0,7
1,0 to 2,0	92,5	92,8	93,5	92,9	0,0 052	94,2	91,6	0,6
2,0 to 5,0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
> 5,0[a]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[a] Extra data.

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