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BSI Standards Publication

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

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National foreword

This British Standard is the UK implementation of EN ISO 29462:2013.

The UK participation in its preparation was entrusted to Technical Committee MCE/21/3, Air filters other than for air supply for I.C. engines and compressors.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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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 (ISO 29462:2013)

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 perte de charge (ISO 29462:2013)

Betriebserprobung von Filtereinrichtungen und -systemen für die allgemeine Lüftung hinsichtlich ihrer Abscheideeffizienz im eingebautem Zustand bezogen auf die Partikelgröße und den Druckverlust (ISO 29462:2013)

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Foreword

This document (EN ISO 29462:2013) has been prepared by Technical Committee ISO/TC 142 "Cleaning equipment for air and other gases" in collaboration with Technical Committee CEN/TC 195 “Air filters for general air cleaning” the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2013, and conflicting national standards shall be withdrawn at the latest by September 2013.

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Endorsement notice

The text of ISO 29462:2013 has been approved by CEN as EN ISO 29462:2013 without any modification.

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 29462 was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

Introduction

The purpose of this International Standard 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 could theoretically be tested using this International Standard, it may 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 will 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 will 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 International Standard.

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 will therefore have lower accuracy and so the results should be interpreted with respect to this.

During in-situ measurement conditions, the optical properties of the particles may differ from the optical properties of the particles used for calibrating the particle counter and testing it in the laboratory. Thus the particle counter could 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 will 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 may 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 may result in lower accuracy and precision in the calculated fractional efficiencies compared to laboratory measurements. This International Standard 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 International Standard is not intended to serve as a filter performance rating method. <u>The results obtained from the test method described in this International Standard do not replace those obtained through tests conducted in the laboratory.</u>

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

1 Scope

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

2 Normative references

The following referenced documents 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.

ISO 7726, *Ergonomics of the thermal environment — Instruments for measuring physical quantities*

ISO 14644-3, *Cleanrooms and associated controlled environments — Part 3: Test methods*

ISO 21501-4, *Determination of particle size distribution — Single particle light interaction methods — Part 4: Light scattering airborne particle counter for clean spaces*

3 Terms, definitions, and abbreviations

3.1 Terms and definitions

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

3.1.1
air filter bypass
unfiltered air that has passed through the AHU filter installation but remained unfiltered because it bypassed the installed air filters

3.1.2
air velocity
rate of air movement at the filter

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

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

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

3.1.5
diluter
dilution system
system for reducing the sampled concentration to avoid coincidence error in the particle counter

3.1.6
filter efficiency
removal efficiency of a filter as determined by this International Standard, where upstream and downstream particle count measurements are taken close to the filter being tested

3.1.7
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

3.1.8
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

3.1.9
isoaxial sampling
sampling in which the flow in the sampler inlet is moving in the same direction as the flow being sampled

3.1.10
isokinetic sampling
technique for air sampling such that the probe inlet air velocity is the same as the velocity of the air surrounding the sampling point

[Source: ISO 29464:2011; 3.1.144]

3.1.11
particle counter
device for detecting and counting numbers of discrete airborne particles present in a sample of air

[Source: ISO 29464:2011; 3.1.27]

3.1.12
particle size range
defined particle counter channel

3.1.13
reference filter
small dry media-type filter that has been laboratory tested for removal efficiency by particle size

3.1.14
removal efficiency by particle size
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

3.1.15
resistance to airflow
loss of static pressure caused by the filter and filter loading which is measured with the filter operating at the measured air velocity

Note 1 to entry: It is expressed in Pa (in WG) to two significant figures.

3.1.16
system efficiency
removal efficiency of a filter system where upstream and downstream particle count measurements may be across several filter banks or other system components

3.2 Abbreviations

AHU	Air Handling Unit
CV	Coefficient of Variation
HEPA	High Efficiency Particle Air (as per ISO 29463-1)
HVAC	Heating, Ventilating and Air-Conditioning
MERV	Minimum Efficiency Reporting Value
OPC	Optical Particle Counter
RH	Relative Humidity
ULPA	Ultra Low Penetration Air
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 — 5,0 μm, in a minimum of four ranges with a minimum of two ranges below 1,0 μm (for example: 0,3 μm — 0,5 μm, 0,5 μm — 1,0 μm, 1,0 μm — 2,0 μm and 2,0 μm — 5,0 μm). For maintenance and calibration of the particle counter, see 4.9

4.2 Diluter

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

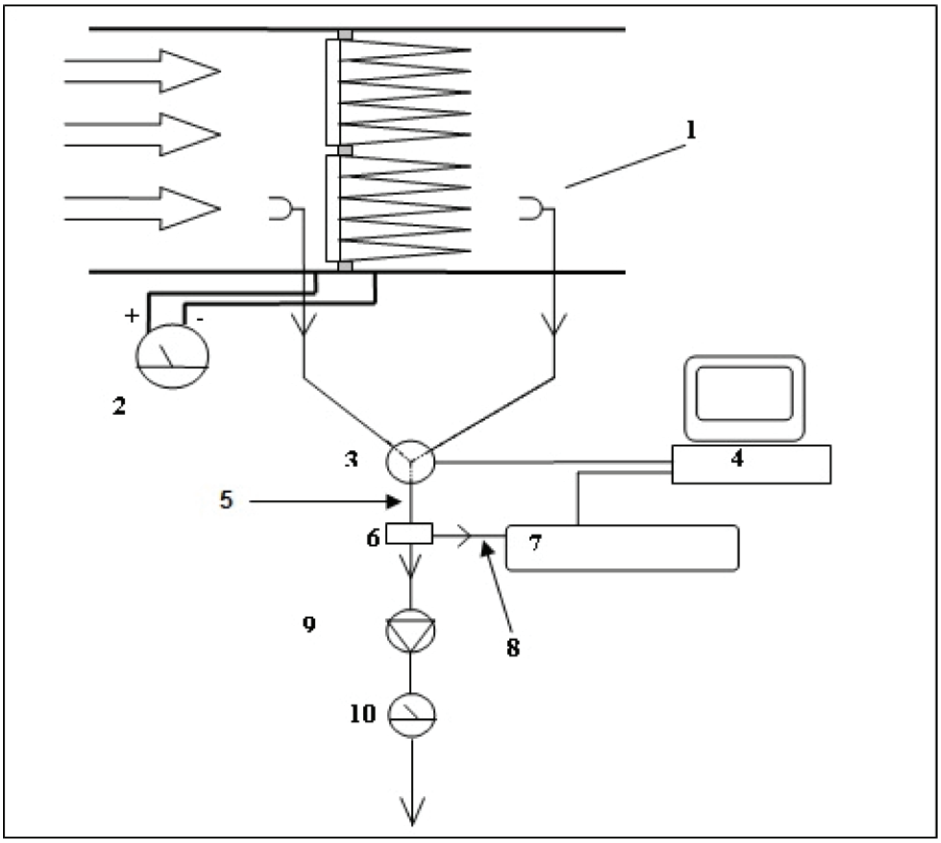
4.3 Pump

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 sampling downstream
2 manometer
3 valve
4 Computer
5 q_s – primary flow
6 diluter
7 particle counter
8 q_{pc} – flow to particle counter
9 pump
10 flow meter

Figure 1 — Sampling system

4.4.2 Sampling probes

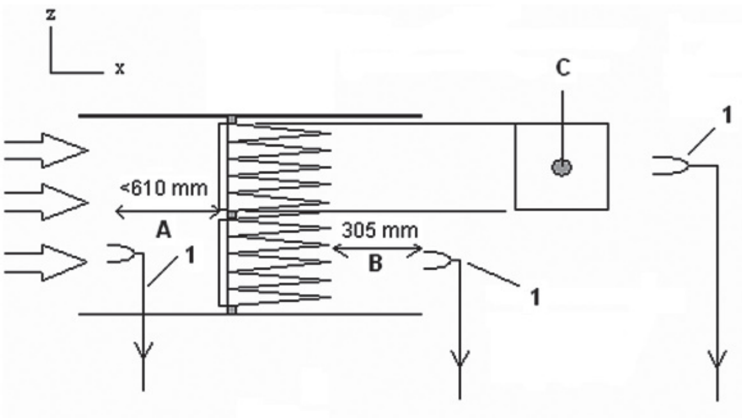
The sampling probe should consist of a sharp edged nozzle connected to the sample line leading to the auxiliary pump or particle counter. The diameter of the nozzle is dependent on the sample flow (q_s) in order to get isokinetic sampling. The diameter should not be less than 8 mm.

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 filters, frames, doors, etc. Measurement 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.



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 downstream sampling probe location for filtration system efficiency test

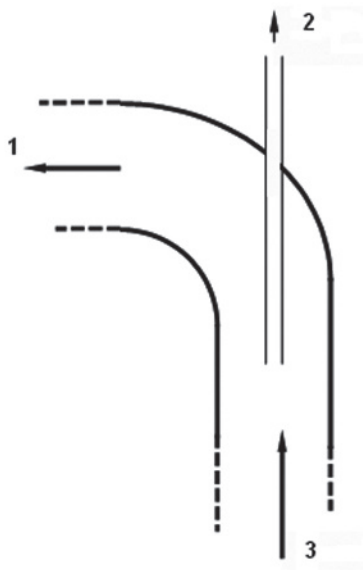
Figure 2 — Sample locations

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 may 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

1 pump flow

2 q_{pc} – flow to particle counter

3 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 will average those values is recommended. Ideally, the instrument should have the ability to correct measurements to standard sea level conditions.

4.6 Relative humidity measurement instrument

The instrument used to measure the relative humidity of the system airflow should have sufficient operational limits such that the system relative humidity is within the limits of the instrument and should be chosen in accordance with ISO 7726. An instrument that records data values and will average 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 will average 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 will average 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 may alter performance	Comment
Particle counter zero check	X			
Sampling system zero check	X			
Resistance to airflow	X			
Air velocity	X			
Temp, 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	
Temp, RH, air velocity, resistance to airflow equipment calibration		X*	X	* or as required by equipment manufacturer
Dilution system ratio check		X	X	
Check sample probes for damage	X			

5 Site evaluation

5.1 General

This section identifies the recommended minimum site requirements for performing a 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 International Standard. It is also used to gauge whether any potentially hazardous conditions exist that would exclude or restrict access to the air handling unit.

Items to inspect include (but are not limited to) those provided in Annex A.

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 may 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 (CV) (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. Preferably, air velocity measurements should be conducted before and after the resistance to airflow and removal efficiency testing, with the velocity measurements averaged.

EXAMPLE

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

2nd test: resistance to airflow measurements

3rd test: removal efficiency testing

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

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

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

6.2 Relative humidity

The instrument(s) identified in 4.6 should be used for these measurements. The relative humidity (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 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 will read 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 will 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 will be recorded for each filter bank separately. However, in some cases the resistance value recorded will be a combination of multiple filters in series as it will 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 CV should be calculated and recorded for this data.

6.5 Removal efficiency

6.5.1 Removal efficiency tests

There are three types of tests described herein.

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.

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).

Other “system” tests

In addition to measuring filtration performance at the air filtration installation, this International Standard may 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 International Standard 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) may affect the downstream particle concentrations.

For 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 may 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 seconds, 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/l (1 048 counts/ft^3).

In some systems the minimum sample volume required may 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 may not be 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 1 minute count. The sum of the concentration of particles in all size ranges shall be less than 10 counts/l (280 counts/ft^3).

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 particle counter's maximum measurable concentration as defined in 3.1.3. 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 1 minute particle count through 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/l (280 counts/ft^3). An example is shown below.

EXAMPLE

Measured concentration =	35 300 counts/l (1 000 000 counts/ft^3)
Maximum leak rate =	0,05 %
Allowable concentration =	18 counts/l (500 counts/ft^3)

6.5.2.7 Isokinetic sampling

Sampling errors can occur when the collection air velocity (i.e. in the sampling probe) is different than 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 (Figure 1). A supplemental pump may be used if needed. Isoaxial sampling to the particle counter is acceptable (Figure 3).

EXAMPLE Assume a measured air velocity of 1,65 m/s (325 fpm) and a probe diameter of 13 mm (0,51 in.)

Sample flow (q_s) m^3/s (cfm) =

$$\frac{[\text{dia(mm)}]^2\pi}{4} \times \frac{1\text{m}^2}{1\times 10^6\text{mm}^2} \times \text{Vel}\,{}^{\text{m}}\!/\!{}_{\text{s}}$$

or

$$\frac{[\text{dia(in)}]^2\pi}{4} \times \frac{1\text{ft}^2}{144\text{in}^2} \times \text{Vel}\,{}^{\text{ft}}\!/\!{}_{\text{min}}$$

$$q_s = \frac{(13\text{mm})^2\pi}{4} \times \frac{1\text{m}^2}{1\times 10^6\text{mm}^2} \times 1{,}65\,{}^{\text{m}}\!/\!{}_{\text{s}}$$

q_s = 2,19 x 10^{-4} m^3/s (0,46 cfm)

The q_s flow should be set as close as possible to the calculated q_s 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. Further, if the differential is too large and the main flow velocities large, some of the dynamic head may 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. In practice, it is generally recommended that the sampling flows be within 20 % of the main flow rates. 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, to prevent impaction losses, particularly of larger particles, it is also good practice to use sample probes with aerodynamic entrance cross-sections and without large flat surfaces.

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 may result in lower precision in the calculated fractional efficiencies. As a result, if the CV (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 CV 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 (6) 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 may 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 may lead to lower uncertainty values as calculated in Clause 9.

6.6 Sampling probes

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 (CV<25 %).

Location of upstream sampling probe

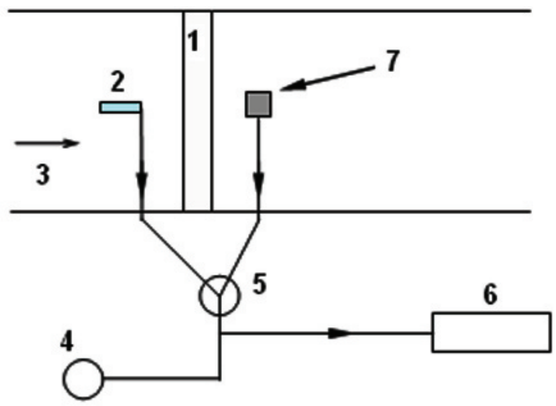
Upstream sampling probes should be positioned so that a representative sample of the upstream concentration is obtained. The inlet of the probe upstream of the filter should be located within 610 mm (24 in.) upstream of the filter surface as shown in Figure 2.

Location of downstream sampling probe — Filter efficiency test

For filter efficiency tests, the inlet of the probe downstream of the filter should be located 305 mm (12 in.) 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 in.) downstream of the filters [e.g. if the coils are positioned within 305 mm (12 in.) of the filters], then it is permissible to locate the probe less than 305 mm (12 in.) from the filters, but not within the volume of the filter (e.g. between pleats, pockets, or in the filter media).

Location of downstream sampling probe — 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 could 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 may 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.



Key

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

Figure 4 — Checking zero count at downstream sampling line

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 Annexes A and B). In addition, a completed test report shall include the following:

a) Owner information

— Name, address, phone, e-mail

— Building

— AHU

— System description

b) Test/AHU information

— Test date & time

— Filter installation date

— Location of test filter(s) in bank

— Schematic drawing of the installation showing sample points for resistance to airflow and particle sampling

— Was diluter used?

— Probe locations

  — Upstream

  — Downstream

— 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 could influence the results)

c) Filter description

— Filter model(s)/description(s)

— Part number(s)/identification number(s)

— Filter size(s) and quantity for each size

— Media type (fiberglass, charged synthetic, etc.)

— 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 (cfm)
  - Particle size ranges
  - 5 % coincidence value
- Temperature
  - Manufacturer and model number
  - Calibration date
- Relative humidity
  - Manufacturer and model number
  - Calibration date
- Resistance to airflow
  - Manufacturer and model number
  - Calibration date
- Air velocity
  - 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 CV 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) Relative humidity

   i) The relative humidity of the air within the system shall be reported.

   ii) The relative humidity 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 CV 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 — 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 — 5,0 µm available from the particle counter.

iii) The CV values shall be calculated and reported for each particle size channel within the range 0,3 µm — 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 will ensure that the measurements are as close to error-free as possible. This section 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 as discussed in previous sections will at least ensure that any systematic errors in the measurements are minimized.

8.2 Relative humidity

High relative humidity, typically above 80 %, can cause variations in efficiency and can increase the resistance to airflow. High relative humidity increases the size of hygroscopic particles. Particles may dry before reaching the detection chamber in the particle counter and have a different size than 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 will 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 may lead to errors in the data. To minimize such errors, it is recommended that the system evaluation procedures discussed in the previous sections be strictly 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 recommended to reduce the measured concentration to within acceptable limits. As per ISO 21501-4, 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 — 1,0 µm.

Errors due to particle losses may 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 will reduce diffusion losses. Loss of larger particles may 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 earlier sections 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 may be easily obtained by measuring the particle concentrations before and after the device or section of the sample train in question. One may 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 may 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

Each dataset will consist of multiple samples. Datasets will be 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	

9.1.1 Dataset sample average

In each dataset there will be 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.

9.1.2 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/l (1 048 counts/ft^3). 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”. Use of a diluter to reduce the upstream concentration to a level the particle counter can handle may cause several of the larger particle size ranges to not meet this minimum criterion.

Upstream concentration average:

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

where

$\overline{U}_{d,\text{con}}$ is the average upstream concentration for dataset *d;*

t_s is the sample time of particle counter in seconds;

q_2 is the particle counter flow rate in m^3/s (cfm)
(for velocity in m/s, m^3 shall be converted to l)
(for velocity in fpm, sec shall be converted to min);

$\overline{U}_{d,\text{con}} \geq 37 \text{counts/l}$
or
$\overline{U}_{d,\text{con}} \geq 1048 \text{counts/ft}^3$.

9.1.3 Particle size range efficiency

For each particle size range, there will be 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

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

d is the dataset number of upstream dataset.

9.1.4 Average efficiency by particle size

The efficiency values will then be 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 may 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 (CV)

The coefficient of variation (CV) is the standard deviation of a group of measurements divided by the mean. A CV value below 25 % is generally acceptable for most measured values, except where noted.

$$\mathrm{CV} = \frac{\delta_c}{\overline{E}_c}$$

Table 3 — Distribution variable

Number of samples	Degrees of freedom $v = n - 1$	t
3	2	4,303
4	3	3,182

Table 3 *(continued)*

Number of samples	Degrees of freedom $v = n - 1$	t
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
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

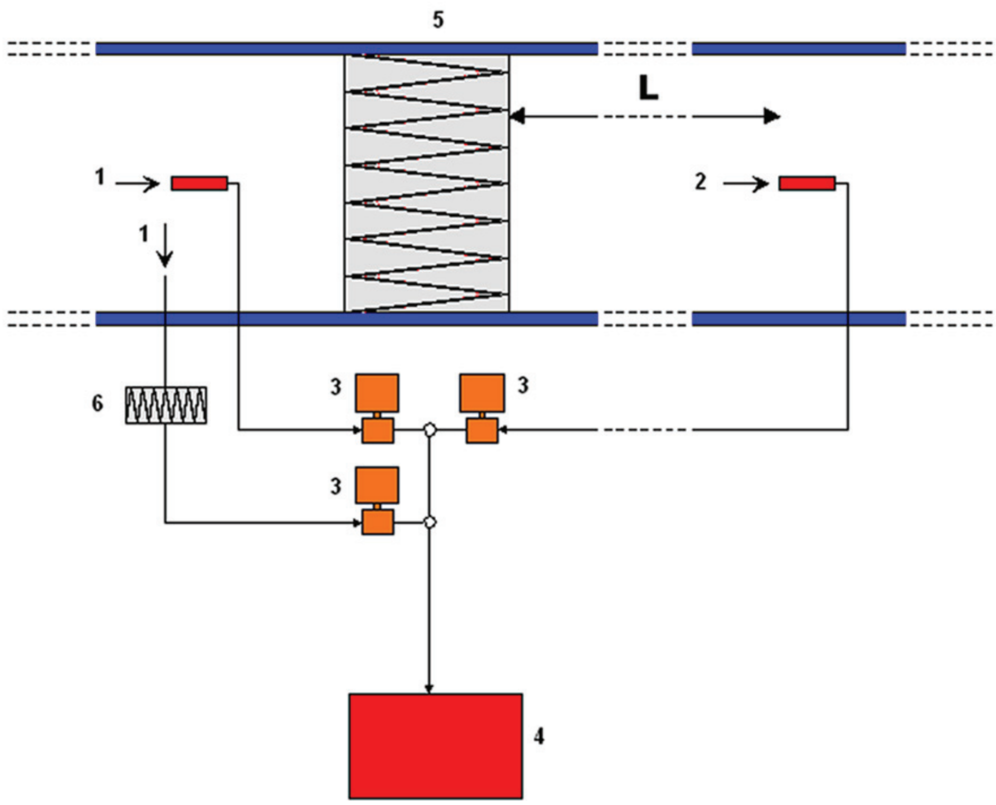
The purpose of the optional enhanced test system is to offer a method of correlation between standard laboratory test data and in-situ test data. By challenging a filter that has been previously tested under laboratory conditions with the same ambient aerosol in-situ, a correlation of the data can be established. This method should be used only where the measured air velocity and particle concentrations are stable, i.e., CV<25 %. The correction of particle sizing can be done only where the particle concentration for that size is statistically stable, i.e., CV<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 will also give 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. The aerosol sampling system is used to measure particle concentrations alternatively from upstream and downstream of the test filter 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 filter using the procedures presented in Clause 9.



Key

1 upstream sample
2 downstream sample
3 valves
4 particle counter
5 test filter
6 reference filter
L distance from test filter to downstream test location

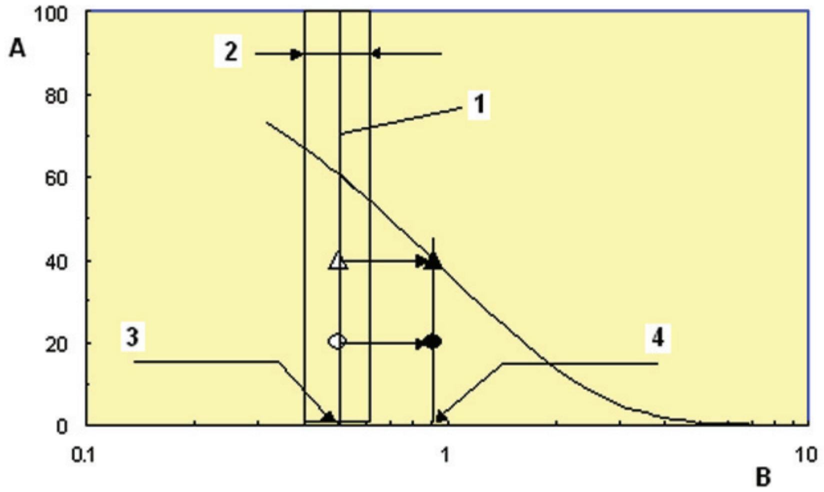
Figure 5 — Schematic of the enhanced test system

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)	D_1			D_2			D_3			D_4			D_5			D_6			D_7
UPSTREAM (U)		U_1			U_2			U_3			U_4			U_5			U_6		
Reference (R)			R1			R2			R3			R4			R5			R6	

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 may differ from the optical properties of the particles used when calibrating the particle counter and when conducting laboratory tests. Thus the particle counter will size the particles differently but will still count the number of the particles correctly. The resulting efficiency/penetration curve will have comparable efficiency values at different particle sizes compared to the laboratory results. The particle sizes can be corrected by comparison to the laboratory penetration (or efficiency) curve of the reference filter as illustrated in Figure 6.



Key

1 reference filter
2 OPC's size channel
3 nominal particle size
4 corrected particle size
A penetration, %
B particle size, µm

△ test result (reference filter)
○ test result (test filter)
▲ corrected result (reference filter)
● corrected result

Figure 6 — Determination of the corrected particle size

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

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 filter measured using ambient particles;

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

Annex A
(informative)

Filter installation pre-testing inspection form

A.1 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 & d/s) of filter banks for probe placement & measurement?			
f.	Adequate space (up/downstream) of other equipment (i.e. coils, fan, etc.) for instrument placement & measurement?			
g.	Sample ports located & labelled (up/downstream) of filter banks?			
h.	Adequate overall interior cleanliness?			
i.	Adequate overall exterior access to AHU?			
j.	Any hazardous conditions (i.e., slip, head knockers, standing water, chemical)?			
k.	Adequate guards provided on the fans & motors?			
l.	Can the airflow through the filters be set to a constant value for the duration of the test			

A.2 Local instrumentation

	Description	Yes	No	Note #
a.	Are differential pressure gauges working properly & calibrated?			
b.	Are pressure taps properly aligned? (i.e., not bent, broken or clogged)			
c.	Is there a velocity gauge working properly & calibrated?			
d.	Is there a temperature gauge working properly & calibrated?			
e.	Is there a relative humidity gauge working properly & calibrated?			

A.3 Filter/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?			

A.4 Utilities

	Description	Yes	No	Note #
a.	Available electric outlet for instrument power?			
b.	Adequate working internal lighting?			

A.5 Filter installation pre-testing inspection form — Notes

Note #	Description

Annex B
(informative)

Approval for testing form

This approval of the two parties 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.

Customer:
Address:

Contractor:
Address:

Number of air handling units:
Environmental parameters to be measured: (Resistance to airflow, air velocity, temperature & relative humidity)
Filter installation testing protocol: ISO 29462 Note: A completed "filter installation pre-testing inspection form" shall accompany this form (see Annex A).

Comments:

Acceptance (Check one box)

With comments:	Without comments	Not accepted

Customer representative:	
Signature:	Date:

Contractor representative:	
Signature:	Date:

Approval for testing form — Air handling units to be tested

The following table identifies the air handling units to be tested by the contractor.

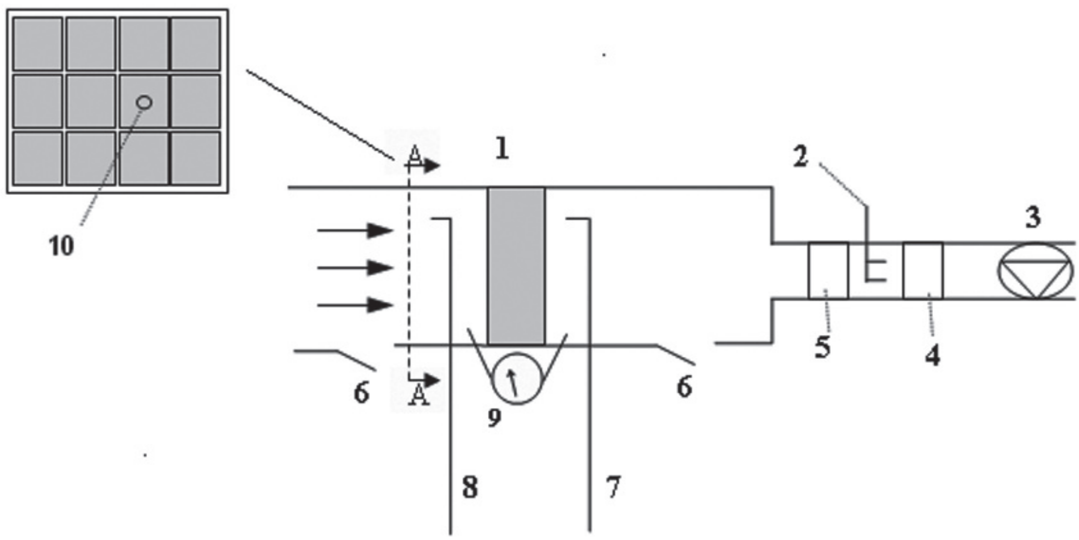
Item #	Building ID	AHU ID

Annex C
(informative)

Example of how to complete testing

C.1 General

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



Key

1	filter installation	7	downstream sample probe
2	humidifier	8	upstream 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

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.2.1 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		
d.	Doors have provision for opening/closure from inside AHU?	X		
e.	Adequate space (u/s & d/s) of filter banks for probe placement & measurement?	X		
f.	Adequate space (up/downstream) of other equipment (i.e. coils, fan, etc.) for instrument placement & measurement?	X		
g.	Sample ports located & labelled (up/downstream) of filter banks?	X		1
h.	Adequate overall interior cleanliness?	X		
i.	Adequate overall exterior access to AHU?	X		
j.	Any hazardous conditions (i.e. slip, head knockers, standing water, chemical)?		X	
k.	Adequate guards provided on the fans & motors?	X		
l.	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 & 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 & calibrated?		X	4
d.	Is there a temperature gauge working properly & calibrated?		X	4
e.	Is there a relative humidity gauge working properly & 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		

Filter installation pre-testing inspection form — Notes

Note #	Description
1	Holes drilled for the particle sampling lines.
2	VFDs will be locked to deliver approximately at 400 fpm for testing.
3	Installed gauges read 0-25 inWG. Not able to read filter resistance. Should be replaced with a 0-2 inWG 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.2.2 Approval for testing form

Customer: Someone's Company, Inc.
Address: 1313 Mockingbird Lane, Some City, Some State, 12345

Contractor: Walrus Testing
Address: 909 Blue Jay Way, Some City, Some State, 12345

Number of air handling units: 2
Environmental parameters to be measured: (Resistance to airflow, air velocity, temperature & relative humidity)
Filter installation testing protocol: ISO 29462 Note: A completed "filter installation pre-testing inspection form" shall accompany this form.

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.

Acceptance (Check one box)

With comments: X	Without Comments:	Not accepted

Customer representative: John Q. Customer	
Signature: John Q. Customer	Date: 02/29/2007

Contractor representative: Seymour Filter	
Signature: Seymour Filter	Date: 02/29/2007

Air handling units to be tested

Item #	Bldg ID	AHU ID
1	12-North Mech Room	AHU 12-01
2	12-North Mech Room	AHU 12-02

C.3 Qualification testing

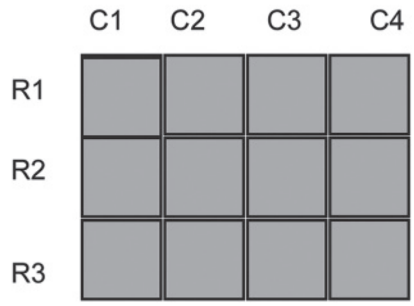
C.3.1 General

The sampling points are located so the influence of turbulence (from door, walls, etc.) 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. Relative humidity 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 filter was selected as the closest filter to the door with a velocity measurement close to the average across the duct.

C.3.2 Velocity data

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

Velocity data set #1 (before any testing)			Velocity data set #2 (after testing)	
Location	**Velocity data m/s (fpm)**		**Location**	**Velocity data m/s (fpm)**
R1-C1	1,65 (324)		R1-C1	1,68 (331)
R1-C2	2,07 (407)		R1-C2	2,09 (411)
R1-C3	1,86 (366)		R1-C3	1,83 (361)
R1-C4	1,91 (376)		R1-C4	1,96 (385)
R2-C1	2,25 (443)		R2-C1	2,29 (451)
R2-C2	2,32 (456)		R2-C2	2,28 (448)
R2-C3	2,04 (402)[a]		R2-C3	2,05 (403)
R2-C4	2,13 (420)		R2-C4	2,11 (416)
R3-C1	2,09 (412)		R3-C1	2,09 (411)
R3-C2	2,14 (421)		R3-C2	2,12 (417)
R3-C3	1,95 (384)		R3-C3	1,99 (392)
R3-C4	2,03 (399)		R3-C4	2,07 (407)
Average	**2,04 (401)**		**Average**	**2,05 (403)**
CV	**8,8%**		**CV**	**8,3%**



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

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

C.3.3 Isokinetic sampling

Calculate the sample flow (q_s) based on the measured average velocity. Sample probe diameter is 13 mm (0,51 in).

Equation:

$$\frac{(13\text{mm})^2 \pi}{4} \times \frac{1\text{m}^2}{1 \times 10^6 \text{mm}^2} \times 2{,}04\,\text{m}/s = 2{,}71 \times 10^{-4}\,\text{m}^3/\text{s}$$

or

$$\frac{(0{,}51\text{in})^2 \pi}{4} \times \frac{1\text{ft}^2}{144\text{in}^2} \times 402\text{fpm} = 0{,}57\text{cfm}$$

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

C.3.4 Temperature and relative humidity

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

Average of 25 readings:

Location	Temp °C (°F)	Temp limits[a] °C (°F)	RH %	RH limits[a] %
In-duct	20,1 (68,2)	1-38 (33-100)	55	10-80
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 —10 Pa, 0 in. — 25 in. WG), the contractor will have to use his instrumentation to measure resistance to airflow.

Conclusion: Based upon the average of 25 readings, the resistance to airflow = 84,6 Pa (0,34 in. 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 1 minute count measurement. If the calculated concentration is lower than the maximum, the test passes.

Total counts in 1 minute:

Cumulative counts (all channels)	**Calculated concentration** counts/l (counts/ft^3)	**Maximum concentration** counts/l (counts/ft^3)
7	2,5 (70)	10 (280)

Counter flow rate: 0,047 l/s (0,1 ft^3/min)

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

Equations:

$$\frac{7\text{particles}}{1\,\text{min}} \times \frac{1}{0{,}047\text{l/s}} \times \frac{1\,\text{min}}{60s} = 2{,}5\text{counts/l}$$

or

$$\frac{7\text{particles}}{1\text{min}} \times \frac{1}{0{,}1\text{ft}^3/\text{min}} = 70\text{counts}\Big/\text{ft}^3$$

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 5 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 1 sample of 20 seconds at each location and determine the average particle count and the CV for the data set. The maximum CV allowable is 25 % unless the average count for any particle size channel is less than 50 particles. For those channels, the CV limit is 50 %.

Size range (µm)	**Differential data** Particles (20 sec samples, 1 location)					**Average particles**	**Standard deviation**	**CV** %	**Maximum CV** %	**Pass or fail**
	R1-C2	R1-C4	R2-C1	R2-C3	R3-C2					
0,3 – 0,5	19 851	16 333	19 724	18 793	16 812	18 303	1 640,1	9,0	25	Pass
0,5 – 0,7	9 123	7 683	8 732	7 981	8 222	8 339	592,1	7,1		Pass
0,7 – 1,0	1 456	1 186	1 379	1 313	1 096	1 286	145,2	11,3		Pass
1,0 – 2,0	623	434	564	411	368	480	108,3	22,6		Pass
2,0 – 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 CV 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 seconds each and determine the average concentration and the CV for the data set. The maximum CV allowable is 25 %.

Size range (µm)	**Differential data** Particles (20 sec samples, 1 location)					**Average particles**	**Standard deviation**	**CV** %	**Maximum CV** %	**Pass or fail**
	1	2	3	4	5					
0,3 – 0,5	18 143	17 880	18 967	20 461	19 488	18 988	1 044,3	5,5	25	Pass
0,5 – 0,7	8 432	7 987	8 321	8 765	8 028	8 307	318,5	3,8		Pass
0,7 – 1,0	1 100	985	1 322	1 213	966	1 117	151,5	13,6		Pass
1,0 – 2,0	527	489	543	518	477	511	27,2	5,3		Pass
2,0 – 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 CV 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.

Upstream concentration data:

Size range (µm)	**Average** (particles)	**Particle concentration** counts/l (counts/ft^3)	**Minimum particle concentration** counts/l (counts/ft^3)	**Pass or fail**
0,3 – 0,5	18 988	20 200 (56 9634)		Pass
0,5 – 0,7	8 307	8 837 (249 198)		Pass
0,7 – 1,0	1 117	1 189 (33 516)		Pass
1,0 – 2,0	511	543 (15 324)		Pass
2,0 – 5,0	27	29 (822)		Fail
>5,0[a]	6	6 (180)	37 (1 048)	Fail
Total	**28 956**			

[a] Extra data.

Conclusion: The concentrations are within the acceptable range for the first four size ranges in the table and no diluter is required. But efficiency should not be reported for the 2,0-5,0 or 5,0-20 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 seconds each and determine the average concentration and the CV for the data set.

Upstream concentration data:

Count number	**Cumulative data** Particles (20 sec)	**Upstream concentration** counts/m3 (counts/ft3)	**Max. concentration**[a] counts/m3 (counts/ft3)
1	28 236	23 987 (847 080)	35 300 (100 000 0)
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.

Counter flow rate: 0,047 l/s (0,1 ft^3/min)

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

Equations:

$$\frac{28956\text{counts}}{20s}\times\frac{1}{0{,}047\,\text{l/s}}=30804\text{counts/l}$$

or

$$\frac{28956\text{counts}}{20s}\times\frac{60\text{s}}{0{,}1\,\text{ft}^3/\text{min}}=868674\text{counts}/\text{ft}^3$$

C.3.8 System zero test

Install a HEPA filter at the downstream probe location air inlet for a minimum of a 1 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.

Total counts in 1 minute:

Cumulative counts (all channels)	**Measured concentration** counts/l (counts/ft3)	**Upstream concentration** counts/l (counts/ft3)	**Allowable concentration** counts/l (counts/ft3)
12	4,3 (120)	30 804 (868 674)	15 (434)

Counter flow rate: 0,047 l/s (0,1 ft^3/min)

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

Equations:

$$\frac{12\text{counts}}{1\,\text{min}}\times\frac{1}{0{,}047\text{l/s}}\times\frac{1\,\text{min}}{60\text{s}}=2{,}5\text{counts/l}$$

or

$$\frac{12\text{counts}}{1\text{min}}\times\frac{1}{0{,}1\text{ft}^3/\text{min}}=120\text{counts}/\text{ft}^3$$

C.4 Filter efficiency data

A minimum of 4 datasets will be collected on the downstream side of one filter location and 3 data sets on the upstream side of the same filter location. Each dataset consists of 6 particle samples of 20 seconds each. Each particle sample provides particle count data for each particle size channel.

C.4.1 Downstream data

The downstream probe was located 305 mm (12 in.) from the back of the test filter at the centre of the filter

Sample dataset:

Size range (µm)	**Downstream dataset 1** (Particles)						**Average particles**
	1	2	3	4	5	6	
0,3 – 0,5	5 004	5 124	4 873	6 023	5 290	5 348	5 277
0,5 – 0,7	1 702	1 721	1 647	1 818	1 857	1 750	1 749
0,7 – 1,0	155	142	138	165	176	161	156
1,0 – 2,0	42	43	32	38	35	28	36
2,0 – 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.4.2 Upstream data

The upstream probe was located 450 mm (18 in.) from the face of the test filter at the centre of the filter.

Sample dataset:

Size range (µm)	**Downstream dataset 1** (Particles)						**Average particles**
	1	2	3	4	5	6	
0,3 – 0,5	19 472	19 813	17 709	19 874	19 038	17 175	18 847
0,5 – 0,7	8 653	8 843	7 789	8 727	8 011	7 943	8 328
0,7 – 1,0	1 267	1 198	954	1 231	1 032	1 001	1 114
1,0 – 2,0	612	585	510	564	417	377	511
2,0 – 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.4.3 Particle count data

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

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 – 0,5	—	18 847	—	18 756	—	17 980	—	18 528	—
	5 277	—	5 428	—	5 127	—	5 102	—	5 234
0,5 – 0,7	—	8 328	—	8 398	—	8 178	—	8 301	—
	1 749	—	1 827	—	1 701	—	1 698	—	1 744
0,7 – 1,0	—	1 114	—	1 201	—	1 056	—	1 124	—
	156	—	171	—	151	—	146	—	156
1,0 – 2,0	—	511	—	499	—	453	—	488	—
	36	—	41	—	31	—	28	—	34
2,0 – 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.4.4 Filter efficiency calculation

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

Size range (µm)	**Efficiency calculations** %			**Average efficiency** %	**Standard deviation**	**95% upper confidence limit** %	**95% lower confidence limit** %	**CV** %
	Eff 1	Eff 2	Eff 3					
0,3 – 0,5	71,6	71,9	71,6	71,7	0,001 7	72,1	71,3	0,2
0,5 – 0,7	78,5	79,0	79,2	78,9	0,003 5	79,8	78,0	0,4
0,7 – 1,0	85,3	86,6	85,9	86,0	0,0064	87,5	84,4	0,7
1,0 – 2,0	92,5	92,8	93,5	92,9	0,0052	94,2	91,6	0,6
2,0 – 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.

C.5 Sample report

International standard ISO 29462 test report

Owner:	Testing firm:
John Q. Customer	Seymour filter
Someone’s Company, Inc.	Walrus Testing
1313 rue Mockingbird	909 Blue Jay Way
Some city, some state, 12345	Some city, some state, 12345
(111) 222-3333	(111) 444-5555
jqc@SomeoneCo.com	filtergeek@WalrusTest.com

System description: This AHU has 12 full size filters operating at approximately 400 fpm (2,03 m/s) 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.

Filter	Manufacturer	Model	Part number	Qty	Size	Media type	Media colour	Estimated media area
PreFilter	FilterGeeks	Pleat8	FilGeek-1	12	24x24x2	Charged Synthetic	White	15 ft^2
Final	FilterGeeks	S-Bag	Fil-GeekB-85-22-8	12	24x24x22 8p	Charged Synthetic	Pink	50 ft^2

Test date and time: February 29, 2007 09:00am

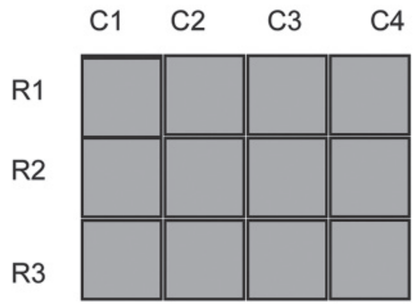
Filter installation date: February 29, 2007

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)

Velocity data set #1 (before any testing)			Velocity data set #2 (after testing)	
Location	**Velocity data** m/s (fpm)		**Location**	**Velocity data** m/s (fpm)
R1-C1	1,68 (331)		R1-C1	1,65 (324)
R1-C2	2,09 (411)		R1-C2	2,07 (407)
R1-C3	1,83 (361)		R1-C3	1,86 (366)
R1-C4	1,96 (385)		R1-C4	1,91 (376)
R2-C1	2,29 (451)		R2-C1	2,25 (443)
R2-C2	2,28 (448)		R2-C2	2,32 (456)
R2-C3	2,05 (403)		R2-C3	2,04 (402)[a]
R2-C4	2,11 (416)		R2-C4	2,13 (420)
R3-C1	2,09 (411)		R3-C1	2,09 (412)
R3-C2	2,12 (417)		R3-C2	2,14 (421)
R3-C3	1,99 (392)		R3-C3	1,95 (384)
R3-C4	2,07 (407)		R3-C4	2,03 (399)
Average	**2,05 (403)**		**Average**	**2,04 (401)**
CV	**8,8%**		**CV**	**8,3%**



a Select position R2-C3 for particle testing.

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

Location	Temp °C (°F)	Temp limits[a] °C (°F)	RH %	RH limits[a] %
In-duct	**20,1 (68,2)**	**1-38 (33-100)**	**55**	**10-80**
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 in. WG) for CV=3,0.

Particle counter zero test (total counts in 1 minute)

Cumulative counts (all channels)	Calculated concentration counts/l (counts/ft^3)	Maximum concentration counts/l (counts/ft^3)
7	**2,5 (70)**	**10 (280)**

Counter flow rate: 0,047 l/s (0,1 ft^3/min)

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

Upstream particle concentrations

Pre-screening of particle concentration in space

Size range (µm)	**Differential data Particles (20 sec samples, 1 location)**					**Average particles**	**Standard deviation**	**CV** %	**Maximum CV** %	**Pass or fail**
	R1-C2	R1-C4	R2-C1	R2-C3	R3-C2					
0,3 – 0,5	19 851	16 333	19 724	18 793	16 812	18 303	16 40,1	9,0	25	Pass
0,5 – 0,7	9 123	7 683	8 732	7 981	8 222	8 339	592,1	7,1		Pass
0,7 – 1,0	1 456	1 186	1 379	1 313	1 096	1 286	1 45,2	11,3		Pass
1,0 – 2,0	623	434	564	411	368	480	108,3	22,6		Pass
2,0 – 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 CV for all six channels is within an acceptable range.

Pre-screening of particle concentration in time

Size range (µm)	**Differential data Particles (20 sec samples, 1 location)**					**Average particles**	**Standard deviation**	**CV** %	**Maximum CV** %	**Pass or fail**
	1	2	3	4	5					
0,3 – 0,5	18 143	17 880	18 967	20 461	19 488	18 988	1 044,3	5,5	25	Pass
0,5 – 0,7	8 432	7 987	8 321	8 765	8 028	8 307	318,5	3,8		Pass
0,7 – 1,0	1 100	985	1 322	1 213	966	1 117	151,5	13,6		Pass
1,0 – 2,0	527	489	543	518	477	511	27,2	5,3		Pass
2,0 – 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 CV for all six channels is within an acceptable range.

Minimum upstream concentration

Upstream concentration data:

Size range (µm)	**Average** (Particles)	**Particle concentration** counts/l (counts/ft³)	**Minimum particle concentration** counts/l (counts/ft³)	**Pass or fail**
0,3 – 0,5	18 988	20 200 (569 634)	37 (1 048)[b]	Pass
0,5 – 0,7	8 307	8 837 (249198)		Pass
0,7 – 1,0	1 117	1 189 (33 516)		Pass
1,0 – 2,0	511	543 (15 324)		Pass
2,0 – 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.

Counter flow rate: 0,047 l/s (0,1 ft³/min)

Conclusion: The concentrations are within the acceptable range for the first four size ranges in the table 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.

Particle concentration limit

Upstream concentration data:

Count number	**Cumulative data** Particles (20 sec)	**Upstream concentration** counts/m³ (counts/ft³)	**Max. concentration**[a] counts/m³ (counts/ft³)
1	28 236	23 987 (847 080)	35 300 (100 000 0)
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.

Counter flow rate: 0,047 l/s (0,1 ft³/min)

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

System zero test

Total counts in 1 minute:

Cumulative counts (all channels)	**Measured concentration** counts/l (counts/ft³)	**Upstream concentration** counts/l (counts/ft³)	**Allowable concentration** counts/l (counts/ft³)
12	**4,3 (120)**	**30 804 (868 674)**	**15 (434)**

Counter flow rate: 0,047 l/s (0,1 ft³/min)

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

Filter efficiency data

Downstream dataset:

Size range (µm)	Downstream dataset 1 (Particles)						Average particles
	1	2	3	4	5	6	
0,3 – 0,5	5 004	5 124	4 873	6 023	5 290	5 348	5 277
0,5 – 0,7	1 702	1 721	1 647	1 818	1 857	1 750	1 749
0,7 – 1,0	155	142	138	165	176	161	156
1,0 – 2,0	42	43	32	38	35	28	36
2,0 – 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.

Upstream dataset:

Size range (µm)	Downstream dataset 1 (Particles)						Average particles
	1	2	3	4	5	6	
0,3 – 0,5	19 472	19 813	17 709	19 874	19 038	17 175	18 847
0,5 – 0,7	8 653	8 843	7 789	8 727	8 011	7 943	8 328
0,7 – 1,0	1 267	1 198	954	1 231	1 032	1 001	1 114
1,0 – 2,0	612	585	510	564	417	377	511
2,0 – 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.

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 – 0,5	—	18 847	—	18 756	—	17 980	—	18 528	—
	5 277	—	5 428	—	5 127	—	5 102	—	5 234
0,5 – 0,7	—	8 328	—	8 398	—	8 178	—	8 301	—
	1 749	—	1 827	—	1 701	—	1 698	—	1 744
0,7 – 1,0	—	1 114	—	1 201	—	1 056	—	1 124	—
	156	—	171	—	151	—	146	—	156
1,0 – 2,0	—	511	—	499	—	453	—	488	—
	36	—	41	—	31	—	28	—	34
2,0 – 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.

Filter efficiency calculation

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