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BSI Standards Publication

Air filters for general ventilation

Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM) (ISO 16890-1:2016)

National foreword

This British Standard is the UK implementation of EN ISO 16890-1:2016. Together with BS EN ISO 16890-2:2016, BS EN ISO 16890-3:2016 and BS EN ISO 16890-4:2016 it supersedes BS EN 779:2012 and DD ISO/TS 21220:2009 which are withdrawn.

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Air filters for general ventilation - Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM) (ISO 16890-1:2016)

Filtres à air de ventilation générale - Partie 1: Spécifications techniques, exigences et système de classification fondé sur l'efficacité des particules en suspension (ePM) (ISO 16890-1:2016)

Luftfilter für die allgemeine Raumlufttechnik - Teil 1: Technische Bestimmungen, Anforderungen und Effizienzklassifizierungssystem basierend auf Feinstaub (PM) (ISO 16890-1:2016)

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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European foreword

This document (EN ISO 16890-1:2016) 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of an identical text or by endorsement, at the latest by June 2017, and conflicting national standards shall be withdrawn at the latest by June 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 779:2012.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

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Endorsement notice

The text of ISO 16890-1:2016 has been approved by CEN as EN ISO 16890-1:2016 without any modification.

Contents

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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 142, *Cleaning equipment for air and other gases*.

This first edition of ISO 16890-1, together with ISO 16890-2, ISO 16890-3 and ISO 16890-4, cancels and replaces ISO/TS 21220:2009, which has been technically revised.

ISO 16890 consists of the following parts, under the general title *Air filters for general ventilation*:

- *Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)*
- *Part 2: Measurement of fractional efficiency and air flow resistance*
- *Part 3: Determination of the gravimetric efficiency and the air flow resistance versus the mass of test dust captured*
- *Part 4: Conditioning method to determine the minimum fractional test efficiency*

Introduction

The effects of particulate matter (PM) on human health have been extensively studied in the past decades. The results are that fine dust can be a serious health hazard, contributing to or even causing respiratory and cardiovascular diseases. Different classes of particulate matter can be defined according to the particle size range. The most important ones are PM$_{10}$, PM$_{2,5}$ and PM$_1$. The U.S. Environmental Protection Agency (EPA), the World Health Organization (WHO) and the European Union define PM$_{10}$ as particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter. PM$_{2,5}$ and PM$_1$ are similarly defined. However, this definition is not precise if there is no further characterization of the sampling method and the sampling inlet with a clearly defined separation curve. In Europe, the reference method for the sampling and measurement of PM$_{10}$ is described in EN 12341. The measurement principle is based on the collection on a filter of the PM$_{10}$ fraction of ambient particulate matter and the gravimetric mass determination (see EU Council Directive 1999/30/EC of 22 April 1999).

As the precise definition of PM$_{10}$, PM$_{2,5}$ and PM$_1$ is quite complex and not simple to measure, public authorities, like the U.S. EPA or the German Federal Environmental Agency (Umweltbundesamt), increasingly use in their publications the more simple denotation of PM$_{10}$ as being the particle size fraction less or equal to 10 µm. Since this deviation to the above mentioned complex "official" definition does not have a significant impact on a filter element's particle removal efficiency, the ISO 16890 series refers to this simplified definition of PM$_{10}$, PM$_{2,5}$ and PM$_1$.

Particulate matter in the context of the ISO 16890 series describes a size fraction of the natural aerosol (liquid and solid particles) suspended in ambient air. The symbol ePM$_x$ describes the efficiency of an air cleaning device to particles with an optical diameter between 0,3 µm and x µm. The following particle size ranges are used in the ISO 16890 series for the listed efficiency values.

Table 1 — Optical particle diameter size ranges for the definition of the efficiencies, ePM$_x$

Efficiency	**Size range**, µm
ePM$_{10}$	0,3 ≤ × ≤10
ePM$_{2,5}$	0,3 ≤ × ≤2,5
ePM$_1$	0,3 ≤ × ≤1

Air filters for general ventilation are widely used in heating, ventilation and air-conditioning applications of buildings. In this application, air filters significantly influence the indoor air quality and, hence, the health of people, by reducing the concentration of particulate matter. To enable design engineers and maintenance personnel to choose the correct filter types, there is an interest from international trade and manufacturing for a well-defined, common method of testing and classifying air filters according to their particle efficiencies, especially with respect to the removal of particulate matter. Current regional standards are applying totally different testing and classification methods, which do not allow any comparison with each other, and thus hinder global trade with common products. Additionally, the current industry standards have known limitations by generating results which often are far away from filter performance in service, i.e. overstating the particle removal efficiency of many products. With this new ISO 16890 series, a completely new approach for a classification system is adopted, which gives better and more meaningful results compared to the existing standards.

The ISO 16890 series describes the equipment, materials, technical specifications, requirements, qualifications and procedures to produce the laboratory performance data and efficiency classification based upon the measured fractional efficiency converted into a particulate matter efficiency (ePM) reporting system.

Air filter elements according to the ISO 16890 series are evaluated in the laboratory by their ability to remove aerosol particulate expressed as the efficiency values ePM$_1$, ePM$_{2,5}$ and ePM$_{10}$. The air filter elements can then be classified according to the procedures defined in this part of ISO 16890. The particulate removal efficiency of the filter element is measured as a function of the particle size in the range of 0,3 µm to 10 µm of the unloaded and unconditioned filter element as per the procedures defined in ISO 16890-2. After the initial particulate removal efficiency testing, the air filter element is conditioned according to the procedures defined in ISO 16890-4 and the particulate removal efficiency is repeated on the conditioned filter element. This is done to provide information about the intensity of any electrostatic removal mechanism which may or may not be present with the filter element for test. The average efficiency of the filter is determined by calculating the mean between the initial efficiency and the conditioned efficiency for each size range. The average efficiency is used to calculate the $e\mathrm{PM}_x$ efficiencies by weighting these values to the standardized and normalized particle size distribution of the related ambient aerosol fraction. When comparing filters tested in accordance with the ISO 16890 series, the fractional efficiency values shall always be compared among the same $e\mathrm{PM}_x$ class (ex. $e\mathrm{PM}_1$ of filter A with $e\mathrm{PM}_1$ of filter B). The test dust capacity and the initial arrestance of a filter element are determined as per the test procedures defined in ISO 16890-3.

INTERNATIONAL STANDARD **ISO 16890-1:2016(E)**

Air filters for general ventilation —

Part 1:
Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)

1 Scope

This part of ISO 16890 establishes an efficiency classification system of air filters for general ventilation based upon particulate matter (PM). It also provides an overview of the test procedures, and specifies general requirements for assessing and marking the filters, as well as for documenting the test results. It is intended for use in conjunction with ISO 16890-2, ISO 16890-3 and ISO 16890-4.

The test method described in this part of ISO 16890 is applicable for air flow rates between 0,25 m^3/s (900 m^3/h, 530 ft^3/min) and 1,5 m^3/s (5 400 m^3/h, 3 178 ft^3/min), referring to a test rig with a nominal face area of 610 mm × 610 mm (24 inch × 24 inch).

ISO 16890 (all parts) refers to particulate air filter elements for general ventilation having an $e\mathrm{PM}_1$ efficiency less than or equal to 99 % when tested according to the procedures defined within ISO 16890-1, ISO 16890-2, ISO 16890-3 and ISO 16890-4. Air filter elements with a higher initial efficiency are evaluated by other applicable test methods (see ISO 29463-1, ISO 29463-2, ISO 29463-3, ISO 29463-4 and ISO 29463-5).

Filter elements used in portable room-air cleaners are excluded from the scope of this part of ISO 16890.

The performance results obtained in accordance with ISO 16890 (all parts) cannot by themselves be quantitatively applied to predict performance in service with regard to efficiency and lifetime. Other factors influencing performance to be taken into account are described in Annex A.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15957, *Test dusts for evaluating air cleaning equipment*

ISO 16890-2, *Air filter for general ventilation — Part 2: Measurement of fractional efficiency and air flow resistance*

ISO 16890-3, *Air filter for general ventilation — Part 3: Determination of the gravimetric efficiency and the air flow resistance versus the mass of test dust captured*

ISO 16890-4, *Air filter for general ventilation — Part 4: Conditioning method to determine the minimum fractional test efficiency*

ISO 29464:2011, *Cleaning equipment for air and other gases — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29464 and the following apply.

3.1 Arrestance and efficiency

3.1.1
arrestance
gravimetric efficiency
A
measure of the ability of a filter to remove mass of a standard test dust from the air passing through it, under given operating conditions

Note 1 to entry: This measure is expressed as a weight percentage.

3.1.2
initial arrestance
initial gravimetric efficiency
A_i
ratio of the mass of a standard test dust retained by the filter to the mass of dust fed after the first loading cycle in a filter test

Note 1 to entry: This measure is expressed as a weight percentage.

3.1.3
average arrestance
average gravimetric efficiency
A_m
ratio of the total mass of a standard test dust retained by the filter to the total mass of dust fed up to final test pressure differential

3.1.4
efficiency
fraction or percentage of a challenge contaminant that is removed by a filter

3.1.5
fractional efficiency
ability of an air cleaning device to remove particles of a specific size or size range

Note 1 to entry: The efficiency plotted as a function of particle size (3.7.1) gives the particle size efficiency spectrum.

[SOURCE: ISO 29464:2011, 3.1.61]

3.1.6
particulate matter efficiency
$e\mathrm{PM}_x$
efficiency (3.1.4) of an air cleaning device to reduce the mass concentration of particles with an optical diameter between 0,3 µm and x µm

3.2
filter element
structure made of the filtering material, its supports and its interfaces with the filter housing

3.3
group designation
designation of a group of filters fulfilling certain requirements in the filter classification

Note 1 to entry: This part of ISO 16890 defines four groups of filters. Group designations are “ISO coarse”, “ISO *e*PM10”, “ISO *e*PM2,5” and “ISO *e*PM1” as defined in Table 4.

3.4 Air flow rates

3.4.1
air flow rate

q_V

volume of air passing through the filter per unit time

[SOURCE: ISO 29464:2011, 3.2.38]

3.4.2
nominal air flow rate

$q_{V,\mathrm{nom}}$

air flow rate (3.4.1) specified by the manufacturer

3.4.3
test air flow rate

$q_{V\mathrm{t}}$

air flow rate (3.4.1) used for testing

3.5 Particulate matter

3.5.1
particulate matter
PM

solid and/or liquid particles suspended in ambient air

3.5.2
particulate matter PM_{10}

particulate matter (3.5.1) which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter

3.5.3
particulate matter $PM_{2,5}$

particulate matter (3.5.1) which passes through a size-selective inlet with a 50 % efficiency cut-off at 2,5 µm aerodynamic diameter

3.5.4
particulate matter PM_1

particulate matter (3.5.1) which passes through a size-selective inlet with a 50 % efficiency cut-off at 1 µm aerodynamic diameter

3.6
particle counter

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

[SOURCE: ISO 29464:2011, 3.27]

3.7 Particle size and diameter

3.7.1
particle size
particle diameter

geometric diameter (equivalent spherical, optical or aerodynamic, depending on context) of the particles of an aerosol

[SOURCE: ISO 29464:2011, 3.1.126]

3.7.2
particle size distribution

presentation, in the form of tables of numbers or of graphs, of the experimental results obtained using a method or an apparatus capable of measuring the equivalent diameter of particles in a sample or capable of giving the proportion of particles for which the equivalent diameter lies between defined limits

[SOURCE: ISO 29464:2011, 3.1.128]

3.8
resistance to air flow
pressure differential

difference in pressure between two points in an airflow system at specified conditions, especially when measured across the filter element (3.2)

3.9
test dust capacity

amount of a standard test dust held by the filter at final test pressure differential

4 Symbols and abbreviated terms

A_i	Initial arrestance, %
d_i	Lower limit particle diameter in a size range *i*, µm
d_{i+1}	Upper limit particle diameter in a size range *i*, µm
$\overline{d}_i$	Geometric mean diameter of a size range *i*, µm
Δd_i	Width of a particle diameter size range *i*, µm
$\Delta\ln d_\text{i}$	Logarithmic width of a particle diameter size range, *i*; ln is the natural logarithm to the base of *e*, where *e* is an irrational and transcendental constant approximately equal to 2,718 281 828 $\Delta \ln d_i = \ln d_{i+1} - \ln d_i = \ln(d_{i+1} / d_i)$, dimensionless
d_{50}	Median particle size of the log-normal distribution, µm
E_i	Initial fractional efficiency of particle size range, *i*, of the untreated and unloaded filter element, % (equals to the efficiency values E_ps of the untreated filter element resulting from ISO 16890-2)
$E_{\text{D},i}$	Fractional efficiency of particle size range, *i*, of the filter element after an artificial conditioning step, % (equals to the efficiency values E_ps of the filter element resulting from ISO 16890-2 after a conditioning step has been carried out according to ISO 16890-4)
$E_{\text{A},i}$	Average fractional efficiency of particle size range *i*, %
$e\text{PM}_{x,\text{ min}}$	Minimum efficiency value with x=1 µm, 2,5 µm or 10 µm of the conditioned filter element, %
$e\text{PM}_x$	Efficiency with x=1 µm, 2,5 µm or 10 µm, %
$q_3(d)$	Discrete particle volume distribution, dimensionless
$Q_3(d)$	Cumulative particle volume distribution, dimensionless
σ_g	Standard deviation of the log-normal distribution

y	Mixing ratio of the bimodal particle size distribution
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
CEN	European Committee for Standardization

5 Technical specifications and requirements

5.1 General

The filter element shall be designed or marked for air flow direction in a way that prevents incorrect mounting.

The filter shall be designed in a way that no leaks occur along the sealing edge when correctly mounted in the ventilation duct. If, for any reason, dimensions do not allow testing of a filter under standard test conditions, assembly of two or more filters of the same type or model are permitted, provided no leaks occur in the resulting filter configuration.

5.2 Material

The filter element shall be made of suitable material to withstand normal usage and exposures to those temperatures, humidities and corrosive environments that are likely to be encountered.

The filter element shall be designed to withstand mechanical constraints that are likely to occur during normal use.

5.3 Nominal air flow rate

The filter element shall be tested at its nominal air flow rate for which the filter has been designed by the manufacturer.

However, many national and association bodies use 0,944 m^3/s (2 000 ft^3/min or 3 400 m^3/h) as nominal air flow for classification or rating of air filters that are nominal 610 mm × 610 mm (24 inch × 24 inch) in face area. Therefore, if the manufacturer does not specify a nominal air flow rate, the filter shall be tested at 0,944 m^3/s. The air flow velocity associated with this air flow rate is 2,54 m/s (500 ft/min).

5.4 Resistance to air flow

The resistance to air flow (pressure differential) across the filter element is recorded at the test air flow rate as described in detail in ISO 16890-2.

5.5 Fractional efficiency curves (particle size efficiency spectrum)

The initial fractional efficiency curve, E_i, of the unloaded and unconditioned filter element as a function of the particle size is measured at the test air flow rate in accordance with ISO 16890-2.

The fractional efficiency curve, $E_{D,i}$, of the filter element after an artificial conditioning step defined in ISO 16890-4 is determined as a function of the particle size in accordance with ISO 16890-2.

5.6 Arrestance

The initial arrestance, the resistance to air flow versus the mass of test dust captured and the test dust capacity are determined in accordance with ISO 16890-3 using L2 test dust as specified in ISO 15957.

6 Test methods and procedure

The technical specifications of the test rig(s), the related test conditions, test aerosols and standard test dust used for this part of ISO 16890 are described in detail in ISO 16890-2, ISO 16890-3 and ISO 16890-4. The full test according to this part of ISO 16890 consists of the steps given below, which all shall be carried out with the same filter test specimen under the same test conditions and at the same test air flow rate:

a) measure the resistance to air flow as a function of the air flow rate according to ISO 16890-2;

b) measure the initial fractional efficiency curve, E_i, of the unloaded and unconditioned filter element as a function of the particle size in accordance with ISO 16890-2;

c) carry out an artificial conditioning step in accordance with ISO 16890-4;

d) measure the fractional efficiency curve, $E_{D,i}$, of the conditioned filter element as a function of the particle size in accordance with ISO 16890-2, which is equal to the minimum fractional test efficiency;

e) calculate the *e*PM efficiencies as defined in Clause 7;

f) load the filter with synthetic L2 test dust as specified in ISO 15957 according to the procedures described in ISO 16890-3 to determine the initial arrestance, the resistance to air flow versus the mass of test dust captured and the test dust capacity (this step is optional for filters of group ISO *e*PM10, *e*PM2,5 or *e*PM1).

The initial fractional efficiency curve, E_i, of the untreated and unloaded filter element (see 5.5) and the fractional efficiency curves, $E_{D,i}$, after an artificial conditioning step are used to calculate the average fractional efficiency curve, $E_{A,i}$, using Formula (1).

$$E_{A,i} = 0{,}5 \cdot (E_i + E_{D,i}) \qquad (1)$$

NOTE For further explanations on the test procedure according to ISO 16890-4, please refer to 8.2.

The procedure described in ISO 16890-4 quantitatively shows the extent of the electrostatic charge effect on the initial performance of the filter element without dust load. It indicates the level of efficiency obtainable with the charge effect completely removed and with no compensating increase in mechanical efficiency. Hence, the fractional efficiencies, $E_{D,i}$, after an artificial conditioning step could underestimate the fractional efficiencies under real service conditions. Since the real minimum fractional efficiencies encountered during service strongly depend on the operating conditions defined by numerous uncontrolled parameters, its real value lays unpredictably between the initial and the conditioned value. For good sense, in this part of ISO 16890, the average between the initial and the conditioned value is used to predict the real fractional efficiencies of a filter during service, as defined by Formula (1). Therefore, it shall be noted that fractional efficiencies measured in real service may differ significantly from the ones given in this part of ISO 16890. Additionally, the chemical treatment of a filter medium applied in ISO 16890-4 as an artificial ageing step may affect the structure of the fibre matrix of a filter medium or chemically affect the fibres or even fully destroy the filter medium. Hence, not all types of filters and media may be applicable to the mandatory procedure described in ISO 16890-4 and, in this case, cannot be classified according to this part of ISO 16890.

7 Classification system based on particulate matter efficiency (*e*PM)

7.1 Definition of a standardized particles size distribution of ambient air

To evaluate air filters according to their *e*PM efficiencies, standardized volume distribution functions of the particle size are used which globally represent the average ambient air of urban and rural areas, respectively. Typically, in the size range of interest (>0,3 µm), the particle sizes in ambient air are bimodal distributed with a fine and coarse mode. Fine filters, mostly designed to filter out the PM_1 and $PM_{2,5}$ particle size fractions, are evaluated using a size distribution which represents urban areas, while fine filters predominantly designed to filter out the PM_{10} fraction are evaluated using a size distribution which represents rural areas.

NOTE The actual particle size distribution of ambient air depends on many different factors. Hence, depending on the location, the season of the year and the weather conditions, the actual measured particle size distribution may differ significantly from the standardized one given in this part of ISO 16890.

This bimodal distribution is represented by combining lognormal distributions for the coarse and the fine mode as given in Formula (3).

$$f(d,\sigma_{\mathrm{g}},d_{50}) = \frac{1}{\ln\sigma_{\mathrm{g}} \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{\left(\ln d - \ln d_{50}\right)^2}{2\left(\ln\sigma_{\mathrm{g}}\right)^2} \right] \qquad (2)$$

In Formula (2), $f(d,\sigma_{\mathrm{g}},d_{50})$ represents the lognormal distribution function for one mode, coarse or fine, where d is the variable particle size, for which the distribution is calculated, and the standard deviation, σ_{g}, and the median particle size, d_{50}, are the scaling parameters. The bimodal distribution is derived as given in Formula (3) by combining the lognormal distributions for the coarse (B) and the fine (A) mode, weighted with the mixing ratio, y.

$$q_3(d) = \frac{\mathrm{d}\,Q_3(d)}{\mathrm{d}\ln d} = y \cdot f(d,\sigma_{\mathrm{g\,A}},d_{50\,\mathrm{A}}) + (1-y) \cdot f(d,\sigma_{\mathrm{g\,B}},d_{50\,\mathrm{B}}) \qquad (3)$$

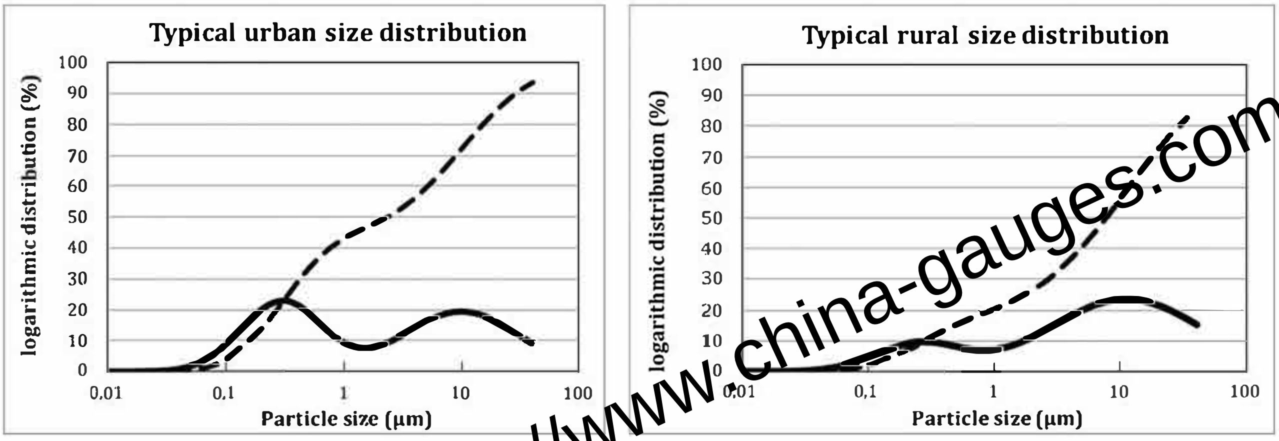
where the parameters are defined to the values given in Table 2, representing urban and rural areas.

Table 2 — Parameters for the distribution function as given in Formula (3) for urban and rural environments

urban $q_{3\mathrm{u}}(\bar{d}_i)$	A	B
$d_{50,\mathrm{u}}$	0,3 µm	10 µm
$\sigma_{\mathrm{g,u}}$	2,2	3,1
y_{u}	0,45	

rural $q_{3\mathrm{r}}(\bar{d}_i)$	A	B
$d_{50,\mathrm{r}}$	0,25 µm	11 µm
$\sigma_{\mathrm{g,r}}$	2,2	4
y_{r}	0,18	

Figure 1 shows a graphical plot of Formula (3) using the parameters given in Table 2.



Key

——— logarithmic distribution (this part of ISO 16890)

— — — logarithmic distribution (cumulative)

Figure 1 — Discrete and cumulative logarithmic particle volume distribution functions of ambient aerosol as typically found in urban and rural environments (see Reference [7])

As an example, Table 3 gives the values of the standardized proportion by volume, q_3, calculated using Formula (3) for the particle counter channels recommended by ISO 16890-2.

Table 3 — Example of the standardized urban and rural particle volume distributions, q_3, in ambient air for the particle size channels recommended by ISO 16890-2

Optical particle diameter in µm				Discrete particle volume distribution	
d_i	d_{i+1}	$\bar{d}_i = \sqrt{d_i \cdot d_{i+1}}$	$\Delta \ln d_i = \ln(d_{i+1} / d_i)$	urban $q_{3u}(\bar{d}_i)$	rural $q_{3r}(\bar{d}_i)$
0,30	0,40	0,35	0,29	0,226 27	0,094 12
0,40	0,55	0,47	0,32	0,198 91	0,083 95
0,55	0,70	0,62	0,24	0,158 37	0,074 32
0,70	1,00	0,84	0,36	0,115 22	0,070 14
1,00	1,30	1,14	0,26	0,085 03	0,076 28
1,30	1,60	1,44	0,21	0,076 18	0,088 33
1,60	2,20	1,88	0,32	0,080 22	0,108 04
2,20	3,00	2,57	0,31	0,099 84	0,137 26
3,00	4,00	3,46	0,29	0,126 88	0,167 08
4,00	5,50	4,69	0,32	0,155 56	0,195 42
5,50	7,00	6,20	0,24	0,177 57	0,216 71
7,00	10,0	8,37	0,36	0,191 57	0,231 43

NOTE The differences between aerodynamic and optical particle diameters are neglected in this part of ISO 16890. Additionally, it is assumed that the particle density is constant while in actual ambient air it may depend on the particle size.

7.2 Calculation of the particulate matter efficiencies (*e*PM)

The particulate matter efficiencies $e\mathrm{PM}_{10}$, $e\mathrm{PM}_{2,5}$ and $e\mathrm{PM}_1$ are calculated from the average fractional efficiencies $E_{\mathrm{A},i}$, [see Formula (1)] and the standardized particle size distribution defined in 7.1 [see Formula (3)] by using Formula (4).

$$e\mathrm{PM}_1 = \sum_{i=1}^{n} E_{\mathrm{A},i} \cdot q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \quad \text{(urban size distribution)},$$

$$e\mathrm{PM}_{2,5} = \sum_{i=1}^{n} E_{\mathrm{A},i} \cdot q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \quad \text{(urban size distribution)},$$

$$e\mathrm{PM}_{10} = \sum_{i=1}^{n} E_{\mathrm{A},i} \cdot q_{3\mathrm{r}}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3\mathrm{r}}(\bar{d}_i) \cdot \Delta \ln d_i \quad \text{(rural size distribution)} \tag{4}$$

where $\bar{d}_i = \sqrt{d_i \cdot d_{i+1}}$ is the geometric mean diameter and $\Delta \ln d_i = \ln d_{i+1} - \ln d_i = \ln(d_{i+1} / d_i)$.

In Formula (4), i is the number of the channel (size range) of the particle counter under consideration and n is the number of the channel (size range) which includes the particle size, x ($d_\mathrm{n} < x \leq d_{\mathrm{n}+1}$), where x = 10 µm for $e\mathrm{PM}_{10}$, x = 2,5 µm for $e\mathrm{PM}_{2,5}$ and x = 1 µm for $e\mathrm{PM}_1$. For the determination of the efficiency $e\mathrm{PM}_1$, the upper limit of the largest channel considered in Formula (4) shall be equal to 1 µm ($d_{\mathrm{n}+1}$ = 1 µm); for $e\mathrm{PM}_{2,5}$ it shall not be larger than 3,0 µm ($d_{\mathrm{n}+1} \leq$ 3,0 µm). To determine the efficiency, $e\mathrm{PM}_{10}$, the upper limit of the largest channel considered in Formula (4) shall be equal to 10 µm ($d_{\mathrm{n}+1}$ = 10 µm). The lower size limit of the smallest channel of the particle counter taken into account for the calculation of the efficiency values, $e\mathrm{PM}_x$ shall be equal to 0,3 µm (d_1 = 0,3 µm). The minimum number of channels considered in Formula (4) shall be 3 for $e\mathrm{PM}_1$ ($n \geq 3$), 6 for $e\mathrm{PM}_{2,5}$ ($n \geq 6$) and 9 for $e\mathrm{PM}_{10}$ ($n \geq 9$). In any case, all channels used shall be adjacent not missing out or overlapping any particle size in-between.

Additionally, the minimum efficiencies, $e\mathrm{PM}_{2,5,\,\mathrm{min}}$ and $e\mathrm{PM}_{1,\,\mathrm{min}}$ are defined by Formula (5).

$$e\mathrm{PM}_{x,\,\mathrm{min}} = \sum_{i=1}^{n} E_{\mathrm{D},i} \cdot q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3\mathrm{u}}(\bar{d}_i) \cdot \Delta \ln d_i \tag{5}$$

7.3 Classification

The initial arrestance and the three efficiency values $e\mathrm{PM}_1$, $e\mathrm{PM}_{2,5}$ and $e\mathrm{PM}_{10}$ and the minimum efficiency values $e\mathrm{PM}_{1,\,\mathrm{min}}$ and $e\mathrm{PM}_{2,5,\,\mathrm{min}}$ shall be used to classify a filter in one of the four groups given in Table 4.

Table 4 — Filter groups

Group designation	Requirement			Class reporting value
	$e\mathrm{PM}_{1,\,\mathrm{min}}$	$e\mathrm{PM}_{2,5,\,\mathrm{min}}$	$e\mathrm{PM}_{10}$	
ISO Coarse	—	—	<50 %	Initial grav. arrestance
ISO *e*PM10	—	—	≥50 %	$e\mathrm{PM}_{10}$
ISO *e*PM2,5	—	≥50 %	—	$e\mathrm{PM}_{2,5}$
ISO *e*PM1	≥50 %	—	—	$e\mathrm{PM}_1$

The filter classes are reported as class reporting value in conjunction with the group designation. For the reporting of the *e*PM classes, the class reporting values shall be rounded downwards to the nearest multiple of 5 % points. Values larger than 95 % are reported as ">95 %". Examples of reporting classes are ISO Coarse 60 %, ISO *e*PM10 60 %, ISO *e*PM2,5 80 %, ISO *e*PM1 85 % or ISO *e*PM1 >95 %. Except for filters of the group ISO Coarse, the dust loading in accordance to ISO 16890-3 and the measurement of the initial arrestance is optional. ISO coarse filters can be classified only based on the initial arrestance and, hence, in this case, the measurement of the $e\mathrm{PM}_x$ efficiency values is optional.

NOTE When the test is carried out on a test rig which was originally designed to perform tests according to the EN 779:2012 only using an aerosol consisting of untreated and undiluted DEHS or an equivalent liquid test aerosol for the size range from 0,3 µm to 1 µm, for an ISO ePM1 dust filter ($e\mathrm{PM}_{1,\,\mathrm{min}} \geq 50\%$), it is allowable only to report the efficiencies $e\mathrm{PM}_{1,\,\mathrm{min}}$ and $e\mathrm{PM}_1$ and, in this case, only to use these two values to determine the filter group and class.

Based on the test results and Table 4, filters could be assigned to two or more filter groups. For example, a filter classified as ISO ePM1 85 % could also be classified as ISO ePM10 95 %. However, according to this part of ISO 16890, filters shall be classified into one individual group only and only this one classification shall be shown on the filter's label. Nevertheless, in a full summary report, all five $e\mathrm{PM}_x$ efficiency values shall be reported, namely the three efficiency values $e\mathrm{PM}_1$, $e\mathrm{PM}_{2,5}$ and $e\mathrm{PM}_{10}$ and the minimum efficiency values $e\mathrm{PM}_{1,\,\mathrm{min}}$ and $e\mathrm{PM}_{2,5,\,\mathrm{min}}$. The reporting of the initial arrestance is optional, except for ISO Coarse filters, where this value determines the filter class and, hence, its reporting is mandatory. The efficiency comparison of different filters shall be done only within the same ISO group, e.g. comparing $e\mathrm{PM}_1$ of filter A with $e\mathrm{PM}_1$ of filter B.

8 Reporting

8.1 General

Data given in the summary report are based on the data and test reports generated from ISO 16890-2, ISO 16890-3 and/or ISO 16890-4 and the data analyses and classification defined in 7.3. At a minimum, the summary test report shall include a description of the test method(s) and any deviations from it. The summary report shall include the following:

- type of filter;
- the number of this part of ISO 16890;
- test number;
- test aerosol;
- test air flow rate;
- summary of the results;
- measured initial fractional efficiency curve as a function of the particle size from a test report according to ISO 16890-2;
- measured fractional efficiency curve as a function of the particle size from a test report according to ISO 16890-2 after an artificial ageing step according to ISO 16890-4;
- calculated average fractional efficiency curve as a function of the particle size according to this part of ISO 16890;
- calculation of the efficiency values $e\mathrm{PM}_{1}$, $e\mathrm{PM}_{2,5}$, $e\mathrm{PM}_{10}$ and of the minimum efficiency values $e\mathrm{PM}_{1,\,\mathrm{min}}$ and $e\mathrm{PM}_{2,5\,\mathrm{min}}$;
- data and results of air flow rate and pressure differential measurements;
- data and results of dust loading measurements (optional).

Test results shall be reported using the summary report format used in this part of ISO 16890 (see Figures 2 to 4, which comprise the complete summary report and are examples of acceptable forms). Exact formats are not requested, but the report shall include the items shown.

As an option, the dust loading curve, test dust capacity and arrestance can be reported for specified final test pressure differentials as defined in ISO 16890-3. Linear interpolation or extrapolation may be used in order to convert the nearest measured values to the specified final test pressure differential.

8.2 Interpretation of test reports

A brief digest shall be included in the test reports. The text given below shall be included after the issued report and shall be a one-page addition filling about half the page:

The interpretation of test reports

This brief review of the test procedures, including those for addressing the testing of electrostatic charged filters, is provided for those unfamiliar with the procedures of this series of ISO standards. It is intended to assist in understanding and interpreting the results in the test report/summary (for further details of procedures, the full ISO 16890 document series shall be consulted).

Air filters may rely on the effects of passive static electric charges on the fibres to achieve high efficiencies, particularly in the initial stages of their working life. Environmental factors encountered in service may affect the action of these electric charges so that the initial efficiency may drop substantially after an initial period of service. This could be offset or countered by an increase in efficiency ("mechanical efficiency") as dust deposits build up. The reported, untreated and conditioned (discharged) efficiency shows the extent of the electrical charge effect on initial performance and indicates the potential loss of particle removal efficiency when the charge effect is completely removed and when, at the same time, there is no compensating increase of the mechanical efficiency. These test results should not be assumed to represent the filter performance in all possible environmental conditions or to represent all possible "real-life" behaviour.

8.3 Summary

The one page summary section of the performance report (see Figure 2) shall include the following information:

a) general:
   1) testing organization including name, location and contact information;
   2) report number;
   3) date of the report;
   4) name of report supervisor;
   5) test(s) requested by;
   6) date when and how the tested device (filter) was obtained;

b) manufacturer's data of the tested device:
   1) manufacturer's name (or name of the marketing organization, if different from the manufacturer);
   2) brand and model name or number as marked on the tested device (full identification of the tested device);
   3) physical description of construction (e.g. pocket filter, number of pockets);
   4) dimensions (width, height, depth);
   5) type of medium – if possible or available, the following shall be described:
      i) identification code (e.g. glass fibre type ABC123, inorganic fibre type 123ABC);
      ii) net effective filtering area as determined by the testing organisation;
   6) additional information if needed;
   7) a photo of the actual test device is highly recommended, but not required;

c) test data:
   1) test air flow rate;
   2) number of the attached test report according to ISO 16890-2;
   3) number of the attached test report according to ISO 16890-4;
   4) number of the attached test report according to ISO 16890-3;

d) results:
   1) initial and final test pressure differential;
   2) efficiency values $e\text{PM}_1$, $e\text{PM}_{2,5}$ and $e\text{PM}_{10}$, including uncertainties;
   3) minimum efficiencies $e\text{PM}_{1,\text{min}}$ and $e\text{PM}_{2,5,\text{min}}$, including uncertainties;
   4) initial and average arrestance (optional for filters of group ISO *e*PM10, ISO *e*PM2,5 or ISO *e*PM1);
   5) test dust capacity (optional);

    6) ISO filter class including test conditions in parentheses, if test air flow rate is non-standard;

e) performance curves:

    1) fractional efficiency versus particle size for the unloaded and untreated filter element resulting from the attached report to ISO 16890-2, and for the filter element after an artificial ageing step resulting from the attached report to ISO 16890-4 and the average fractional efficiency according to this part of ISO 16890;

    2) pressure differential versus test dust captured (optional);

    3) arrestance versus test dust captured resulting from the attached report according to ISO 16890-3 (optional). The curve shall be drawn through arrestance values plotted at the mid-point of their associated weight increments;

f) concluding statement:

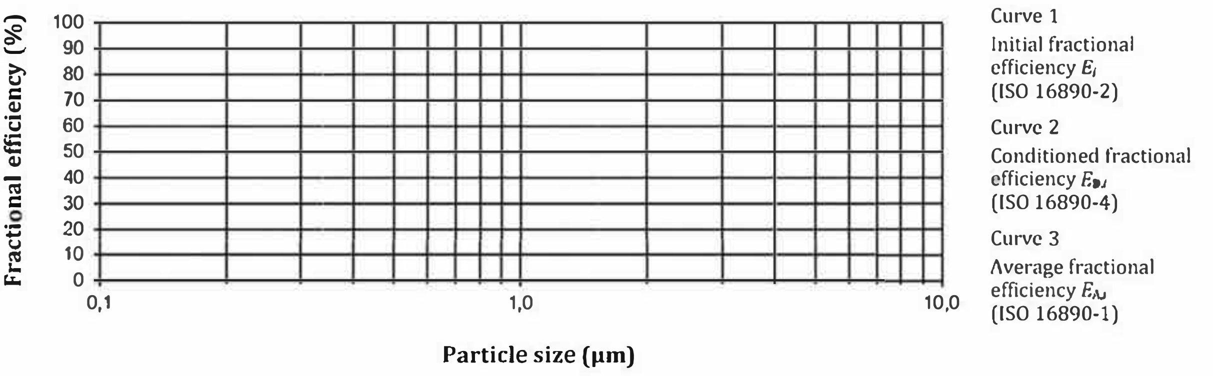
    1) the results of this test relate only to the test device in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict filtration performance in all "real-life" environments.

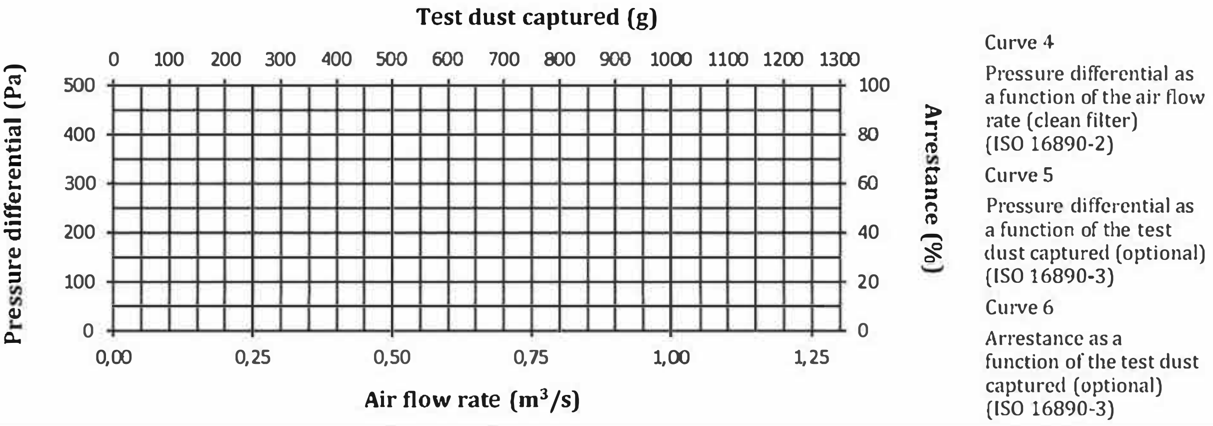
In the summary report, the results shall be rounded to the nearest integer.

Efficiency values and the calculation of the $e\mathrm{PM}_x$ efficiencies shall be attached to the summary report as shown in Figures 3 and 4.

ISO 16890 – Air Filter Test Results		**Testing organisation:** Name Address Phone
GENERAL		
Report no.:		Date of report: yyyy-mm-dd
Supervisor:		Device obtained (when and how obtained)
Test(s) requested by:		
DEVICE TESTED		
Model:	Manufacturer:	Construction:
Type of medium:	Net effective filtering area:	Filter dimensions (width × height × depth): mm × mm × mm
TEST DATA AND ATTACHED TEST REPORTS		
Test air flow rate: m^3/s	Test report to ISO 16890-2	Report no.
	Test report to ISO 16890-3 (optional)	Report no.
	Test report to ISO 16890-4	Report no.

RESULTS					
Initial pressure differential: Pa	Initial arrestance: %	$e\mathrm{PM}_{1,\mathrm{min}}$ %	$e\mathrm{PM}_{2,5,\mathrm{min}}$ %		ISO rating **ISO ePM_ _%**
Final test pressure differential: Pa / Pa / Pa	Test dust capacity: g / g / g	$e\mathrm{PM}_1$ %	$e\mathrm{PM}_{2,5}$ %	$e\mathrm{PM}_{10}$ %	
Remarks:					





NOTE The results of this test relate only to the test device in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict filtration performance in all "real life" environments.

Figure 2 — Summary section of performance report

ISO 16890 — Fractional efficiency values							
Testing organization:					Report no.:		
Model:					Manufacturer:		
Test air flow rate:			m³/s		Date of report: yyyy-mm-dd		
i	d_i µm	d_{i+1} µm	$\overline{d}_i$ µm	$\Delta\ln\ d_i$ µm	E_i %	$E_{D,i}$ %	$E_{A,i}$ %
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Key

d_i	lower limit particle diameter in a size range i, µm
d_i+1	lower limit particle diameter in a size range i, µm
$\overline{d}_i$	geometric mean diameter of a size range i, µm
$\Delta\ln d_i$	logarithmic width of a particle diameter size range i; ln is the natural logarithm to the base of e, where e is an irrational and transcendental constant approximately equal to 2,718 281 828, dimensionless $\Delta\ln d_i = \ln (d_{i+1}/d_i)$
E_i	initial fractional efficiency of particle size range i of the untreated and unloaded filter element, %
$E_{D,i}$	fractional efficiency of particle size range i of the filter element after an artificial conditioning step, %
$E_{A,i}$	average fractional efficiency $(E_i + E_{D,i})/2$ of particle size range i, %

Figure 3 — Efficiency value reporting

ISO 16890 – Calculation of PM-efficiencies	
Testing organisation:	Report no.:
Model:	Manufacturer:
Test air flow rate: m³/s	Date of report: yyyy-mm-dd

i	$\bar{d}_i$ µm	$\Delta\ln d_i$	urban distribution $q_{3u}(\bar{d}_i)$	$q_{3u}(\bar{d}_i) \cdot \Delta\ln d_i$	$E_{D,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta\ln d_i$	$E_{A,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta\ln d_i$	ePM$_{x,min}$ %	ePM$_x$ %
1								
2								
3								
4							**ePM$_{1,\text{min}}$**	**ePM$_1$**
			Σ line 1-4					
5								
6								
7								
8							**ePM$_{2,5,\text{min}}$**	**ePM$_{2,5}$**
			Σ line 1-8					

i	$\bar{d}_i$ µm	$\Delta\ln d_i$	rural distribution $q_{3u}(\bar{d}_i)$	$q_{3r}(\bar{d}_i) \cdot \Delta\ln d_i$		$E_{A,i} \cdot q_{3u}(d_i) \cdot \Delta\ln d_i$		ePM$_x$ %
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								**ePM$_{10}$**
			Σ line 1-12					

Figure 4 — Reporting of calculation of the efficiency values, ePM$_x$

Annex A
(informative)

Shedding from filters

A.1 Shedding

A.1.1 General

The term “shedding” comprises three separate aspects of filter behaviour: re-entrainment of particles, particle bounce and release of fibres or particulate matter from the filter material. Some or all of these phenomena are likely to occur to some extent during the life cycle of an installed filter, especially in dry weather conditions.

Literature about shedding and its effect on filter performances can be found in References [18] and [20] to [25].

A.1.2 Re-entrainment of particles

As the quantity of the arrested dust on the filter increases, the following effects may lead to re-entrainment of already captured particles into the air stream:

- an incoming particle may impact on a captured particle and re-entrain it into the air stream;
- the air velocity in the channels through the medium increases because of the space occupied by captured particles. Furthermore, the filter medium may become compressed by the increased resistance to airflow, thereby causing a further increase in velocity in the air channels. The consequent increased fluid drag on deposited particles may re-entrain some of them;
- movements of the filter medium during operation cause re-arrangement of dust in the filter medium structure. This leads to an immediate re-entrainment of dust. Filter medium movements can be caused by a variety of circumstances, such as:
  a) normal air flow through the filter;
  b) periodic (e.g. daily) start/stop operation of the air conditioning plant;
  c) varying air flow rates, caused by air flow control;
  d) mechanical vibration, caused by the fan or other equipment.

Re-entrainment of particles may be measured and quantified (see References [1], [4], [25] and [26]).

This effect is more pronounced for low efficiency filters than for high efficiency filters (see References [25] and [26]).

A.1.3 Particle bounce

In an ideal filtration process, each particle would be permanently arrested at the first collision with a filtering surface such as a fibre, or with an already captured particle. For small particles and low air velocities, the energy of adhesion greatly exceeds the kinetic energy of the airborne particle in the air stream, and once captured, such particles are very unlikely to be dislodged from the filter. As particle size and air velocity increase, the kinetic energy of particles increases and, hence, larger particles may “bounce” off a fibre. As a result, they normally lose enough energy to be captured in a subsequent collision with a fibre. However, if no contact with a fibre follows, the particle is shed, i.e. discharged from the filter, which results in a corresponding reduction of efficiency for particles of this size range (see References [5] and [6]).

Therefore, as described in ISO 16890-2, to quantify this effect and to consider it in the efficiency measurement, for particles larger than 3 µm, solid KCl particles shall be used as a test aerosol. Using a liquid aerosol, the particle bounce effect cannot be measured at all.

The particle bounce effect is more pronounced for low efficiency filters than for high efficiency filters.

A.1.4 Release of fibres or particulate matter from filter material

Some filter media either contain and/or generate loose fibres, or particulate matter might be emitted from the filter's design materials or the filter medium (e.g. binder, etc). During filter operation, especially in turbulent air flow or during variable air flow or start-stop operation, these materials can be emitted into the air stream. The extent of such shedding depends on the integrity of the medium fibre structure and its rigidity and stability in the face of varying air velocities, as well as the stability of the filter design materials (e.g. the binder which holds fibres together), throughout the operating life of the filter. It should be noted, however, that the quantity of fibres or particulate matter shed in this way is normally negligible in comparison with the total amount of dust penetrating through a filter loaded by typical environmental dust burden (see References [9] and [10]).

A.2 Testing of shedding effects

Users should be aware of the possibility of filters exhibiting shedding behaviour in practical use. From the user's point of view, it would be advantageous to detect any shedding behaviour of a filter. However, such measurements are not that easy to perform. Different attempts have been made in recent years to measure shedding quantitatively, but up to now it has not been possible to define a method which generates reproducible and repeatable test results.

The arrestance measurements for low efficiency filters prescribed in this part of ISO 16890 reflect the shedding effects described above (see A.1) only partly, if at all. However, any drop in the value of the arrestance or resistance during the course of a filter loading test should be taken as a serious indication that shedding may have occurred.

The efficiency/particle size results for higher efficiency filters provided in this part of ISO 16890 reflect normally none of the above described shedding effects, as the aerosol used for these filters is a liquid (DEHS) aerosol.

Membrane sampling downstream of filters and microscopic analyses of the membranes could determine occurrence of this type of shedding, but such a method is not defined here.

Annex B
(informative)

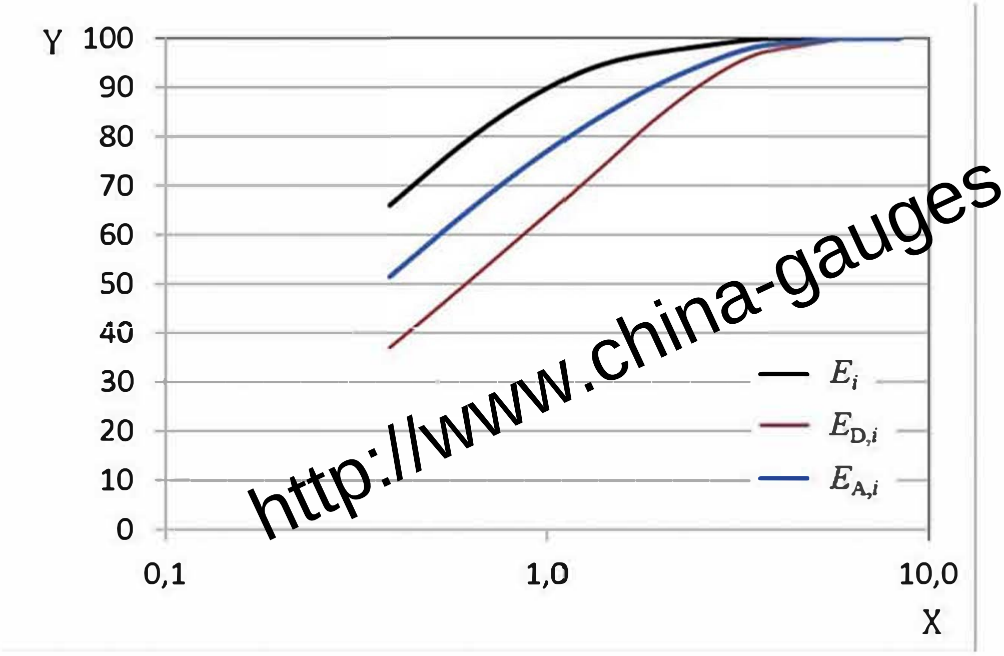
Examples

In this example, measurement results and the calculation and classification method is shown for a synthetic pocket filter (Filter A) classified F7 to EN 779 and MERV-A 14 to ASHRAE 52.2.

*e*PM efficiencies have been calculated by using the MS Excel file included in this part of ISO 16890 (http://standards.iso.org/iso/16890/-1/).

Table B.1 — Example filter data for the fractional efficiency values of Filter A

i	d_i µm	d_{i+1} µm	$\bar{d}_i$ µm	$\Delta \ln d_i$	E_i %	$E_{D,i}$ %	$E_{A,i}$ %
1	0,3	0,5	0,39	0,51	66,0	37,0	51,5
2	0,5	0,7	0,59	0,34	78,0	49,0	63,5
3	0,7	1,0	0,84	0,36	86,3	59,0	72,7
4	1,0	1,3	1,14	0,26	92,0	68,0	80,0
5	1,3	1,6	1,44	0,21	95,0	75,0	85,0
6	1,6	2,2	1,88	0,32	96,9	83,0	90,0
7	2,2	3,0	2,57	0,31	98,4	91,0	94,7
8	3,0	4,0	3,46	0,29	99,7	96,5	98,1
9	4,0	5,5	4,69	0,32	100	98,6	99,3
10	5,5	7,0	6,20	0,24	100	100	100
11	7,0	10,0	8,37	0,36	100	100	100



Key

X particle size (µm)

Y fractional efficiency (%)

Figure B.1 — Example filter data for the fractional efficiency values of Filter A plotted as a function of the particle size (particle size efficiency spectra)

Table B.2 — Example for the calculation of *e*PM efficiencies for Filter A

i	$\bar{d}_i$ µm	$\Delta\ln d_i$	urban $q_{3u}(\bar{d}_i)$	$q_{3u}(\bar{d}_i)$ $\cdot\Delta\ln d_i$	$E_{D,i}\cdot q_{3u}(\bar{d}_i)$ $\cdot\Delta\ln d_i$	$E_{A,i}\cdot q_{3u}(\bar{d}_i)$ $\cdot\Delta\ln d_i$	$e\text{PM}_{x,\text{min}}$ %	$e\text{PM}_x$ %
1	0,39	0,51	0,219 17	0,111 960	0,041 425	0,057 659		
2	0,59	0,34	0,165 68	0,055 745	0,027 315	0,035 398		
3	0,84	0,36	0,115 22	0,041 097	0,024 247	0,029 857	**$e\text{PM}_{1,\text{min}}$**	**$e\text{PM}_1$**
			Σ line 1-3	**0,208 802**	**0,092 988**	**0,122 915**	**45**	**59**
4	1,14	0,26	0,085 03	0,022 309	0,015 170	0,017 847		
5	1,44	0,21	0,076 18	0,015 817	0,011 863	0,013 445		
6	1,88	0,32	0,080 22	0,025 546	0,021 203	0,022 978		
7	2,57	0,31	0,099 84	0,030 966	0,028 179	0,029 324	**$e\text{PM}_{2.5,\text{min}}$**	**$e\text{PM}_{2,5}$**
			Σ line 1-7	**0,303 440**	**0,169 403**	**0,206 510**	**56**	**68**
7	2,57	0,31	0,099 84	0,030 966	0,028 179	0,029 324	**$e\text{PM}_{2.5,\text{min}}$**	**$e\text{PM}_{2,5}$**
1	0,39	0,51	0,090 88	0,046 422		0,023 908		
2	0,59	0,34	0,075 71	0,025 474		0,016 176		
3	0,84	0,36	0,070 14	0,025 016		0,018 174		
4	1,14	0,26	0,076 28	0,020 013		0,016 011		
5	1,44	0,21	0,088 33	0,018 340		0,015 589		
6	1,88	0,32	0,108 04	0,034 406		0,030 949		
7	2,57	0,31	0,137 26	0,042 573		0,040 316		
8	3,46	0,29	0,167 08	0,048 067		0,047 154		

Table B.2 *(continued)*

i	$\bar{d}_i$ µm	$\Delta \ln d_i$	urban $q_{3u}(\bar{d}_i)$	$q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	$E_{D,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	$E_{A,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	ePM$_{x,\text{min}}$ %	ePM$_x$ %
9	4,69	0,32	0,195 42	0,062 233		0,061 798		
10	6,20	0,24	0,216 71	0,052 261		0,052 261		
11	8,37	0,36	0,231 43	0,082 545		0,082 545		**ePM$_{10}$**
			Σ line 1-11	**0,457351**		**0,404 879**		**89**

NOTE The data above are rounded. Since for the data calculation the actual formulae have been used with more digits than given above, there might be some rounding differences when recalculating the data with the values given above.

In the example above, the filter is rated according to Table 4 as ISO *e*PM2,5 65 %.

Another example is the one of a glass-fibre paper based rigid filter (Filter B) classified F9 to EN 779 and MERV-A 15 to ASHRAE 52.2.

Table B.3 — Example filter data for the fractional efficiency values of Filter B

i	d_i in µm	d_{i+1} in µm	$\bar{d}_i$ in µm	$\Delta \ln d_i$	E_i %	$E_{D,i}$ %	$E_{A,i}$ %
1	0,3	0,5	0,39	0,51	82,0	79,0	80,5
2	0,5	0,7	0,59	0,34	90,0	88,0	89,0
3	0,7	1,0	0,84	0,36	94,3	93,0	93,7
4	1,0	1,3	1,14	0,26	96,7	96,0	96,4
5	1,3	1,6	1,44	0,21	98,2	98,0	98,1
6	1,6	2,2	1,88	0,32	98,8	98,5	98,7
7	2,2	3,0	2,57	0,31	98,9	98,7	98,8
8	3,0	4,0	3,46	0,29	99,2	99,0	99,1
9	4,0	5,5	4,69	0,32	99,7	99,6	99,7
10	5,5	7,0	6,20	0,24	100	100	100
11	7,0	10,0	8,37	0,36	100	100	100

Table B.4 — Example for the calculation of the *e*PM efficiencies for Filter B

i	$\bar{d}_i$ in µm	$\Delta \ln d_i$	urban distribution $q_{3u}(\bar{d}_i)$	$q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	$E_{D,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	$E_{A,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i$	ePM$_{x,\text{min}}$ %	ePM$_x$ %
1	0,39	0,51	0,219 17	0,111 960	0,088 449	0,090 128		
2	0,59	0,34	0,165 68	0,055 745	0,049 056	0,049 613		
3	0,84	0,36	0,115 22	0,041 097	0,038 220	0,038 488	**ePM$_{1,\text{min}}$**	**ePM$_1$**
			Σ line 1-3	**0,208 802**	**0,175 725**	**0,178 229**	**84**	**85**
4	1,14	0,26	0,085 03	0,022 309	0,021 417	0,021 495		
5	1,44	0,21	0,076 18	0,015 817	0,015 501	0,015 517		
6	1,88	0,32	0,080 22	0,025 546	0,025 163	0,025 201		
7	2,57	0,31	0,099 84	0,030 966	0,030 563	0,030 594	**ePM$_{2.5,\text{min}}$**	**ePM$_{2,5}$**
			Σ line 1-7	**0,303 440**	**0,268 368**	**0,271 035**	**88**	**89**

Table B.4 *(continued)*

i	$\overline{d}_i$ in µm	$\Delta\ln d_i$	urban distribution $q_{3u}(\overline{d}_i)$	$q_{3u}(\overline{d}_i) \cdot \Delta\ln d_i$	$E_{D,i} \cdot q_{3u}(\overline{d}_i) \cdot \Delta\ln d_i$	$E_{A,i} \cdot q_{3u}(\overline{d}_i) \cdot \Delta\ln d_i$	ePM$_{x,\ min}$ %	ePM$_x$ %
1	0,39	0,51	0,090 88	0,046 422		0,037 370		
2	0,59	0,34	0,075 71	0,025 474		0,022 672		
3	0,84	0,36	0,070 14	0,025 016		0,023 428		
4	1,14	0,26	0,076 28	0,020 013		0,019 283		
5	1,44	0,21	0,088 33	0,018 340		0,017 991		
6	1,88	0,32	0,108 04	0,034 406		0,033 942		
7	2,57	0,31	0,137 26	0,042 573		0,042 062		
8	3,46	0,29	0,167 08	0,048 067		0,047 634		
9	4,69	0,32	0,195 42	0,062 233		0,062 016		
10	6,20	0,24	0,216 71	0,052 261		0,052 261		
11	8,37	0,36	0,231 43	0,082 545		0,082 545		***e*PM$_{10}$**
			Σ line 1-11	**0,457 351**		**0,441 203**		**96**

NOTE The data above are rounded. Since for the data calculation the actual formulae have been used with more digits than given above, there might be some rounding differences when recalculating the data with the values given above.

In the example above, the filter is rated according to Table 4 as ISO *e*PM1 85 %.

Annex C
(informative)

Estimation of downstream fine dust concentrations

This is an example on how this part of ISO 16890 could be used for the estimation of PM_x concentrations in the air downstream of the filter, if the upstream, PM_x, concentration, $C_{up}(PM_x)$, is known. An estimate for downstream concentration, $C_{down}(PM_x)$, can be calculated using Formula (C.1).

$$C_{down}(PM_x) = C_{up}(PM_x) \cdot (1 - ePM_x) \tag{C.1}$$

In Formula (C.1), the ePM_x efficiencies ePM_{10}, $ePM_{2,5}$ and ePM_1 are the ones derived from this part of ISO 16890 for the filter type under concern.

As an example, it shall be assumed that the concentration upstream of a filter stage is 15 µg/m³ for $PM_{2,5}$ and 40 µg/m³ for PM_{10}. The efficiency values ePM_x of a filter stage shall be $ePM_{2,5}$ = 68 % = 0,68 and ePM_{10} = 89 % = 0,89 (example Filter A in Annex B). Using Formula (C.1) the downstream concentrations are calculated as:

$$C_{down}(PM_{2,5}) = 15\ \mu g/m^3 \cdot (1 - 0{,}68) = 4{,}8\ \mu g/m^3$$

$$C_{down}(PM_{10}) = 40\ \mu g/m^3 \cdot (1 - 0{,}89) = 4{,}4\ \mu g/m^3 \tag{C.2}$$

NOTE Real concentration values can differ from the calculation depending on operation conditions of the filters and the actual ambient aerosol particle size distribution (deviation from the ones assumed in this part of ISO 16890).

NOTE As $PM_{2,5}$ is a sub-fraction of PM_{10}, in actual ambient aerosol it is impossible for $C_{down}(PM_{10})$ to be smaller than $C_{down}(PM_{2,5})$. In this case, the difference results from the fact that two different ambient aerosol distributions (rural and urban) are defined to calculate $ePM_{2,5}$ and ePM_{10}. If this occurs when estimating the concentrations downstream of an air filter, where $C_{down}(PM_{10})$ is smaller than $C_{down}(PM_{2,5})$, it shall be assumed that $C_{down}(PM_{10}) = C_{down}(PM_{2,5})$.

As the fractional efficiency of an air filter depends on the particle size, the normalized downstream particle size distribution differs significantly to the one upstream of a filter (see Figures C.1 and C.2). As the ePM_x efficiencies derived from this part of ISO 16890 have been calculated by assuming a standardized particle size distribution and as the distribution downstream of a filter significantly differs from this standardized distribution, Formula (C.1) cannot be used with the ePM_x efficiencies derived from this part of ISO 16890 of the individual following filter stages. However, the methodology of this part of ISO 16890 can also be applied to calculate a cumulated efficiency value, $ePM_{x,cum}$, of a multi-stage filter system using Formula (4) with the cumulated fractional efficiency, $E_{cum,i}$.

$$ePM_{x,\,cum} = \sum_{i=1}^{n} E_{cum,i} \cdot q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3u}(\bar{d}_i) \cdot \Delta \ln d_i \text{ for } x = 1\ \mu m \text{ and } x = 2{,}5\ \mu m$$

$$ePM_{x,\,cum} = \sum_{i=1}^{n} E_{cum,i} \cdot q_{3r}(\bar{d}_i) \cdot \Delta \ln d_i \Big/ \sum_{i=1}^{n} q_{3r}(\bar{d}_i) \cdot \Delta \ln d_i \text{ for } x = 10\ \mu m \tag{C.3}$$

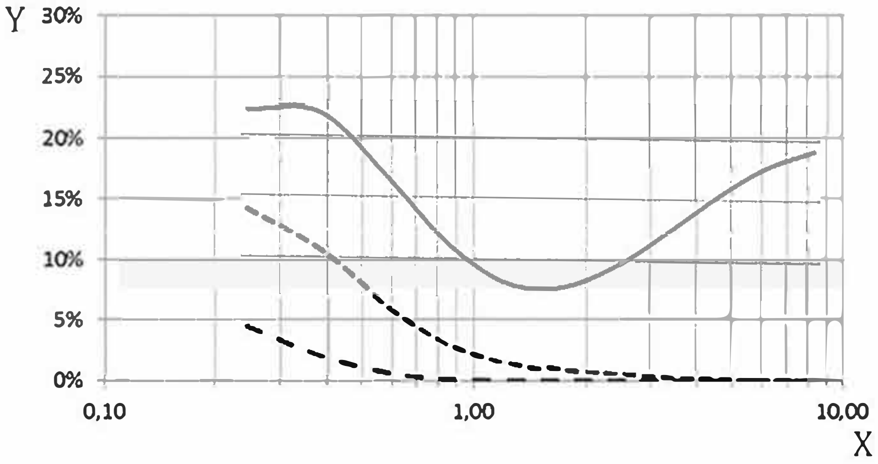
where $E_{cum,i} = 1 - \prod_{j=1}^{k} \left[1 - E_{A,i}(\text{Filter } j) \right]$, j is the number of the filter stage and k the total number of stages

In case of a multi-stage filter system, the PM concentration downstream of the final filter stage can then be calculated using the cumulated efficiency $e\text{PM}_{x,\ \text{cum}}$ in Formula (C.1). Using the filter data given as example for Filter A and B in Annex B, this results in the example data shown in the Table C.1 and C.2 below. Table C.1 shows the data resulting from the typical urban particle size distribution, while Table C.2 shows the data resulting from a typical rural one (see Table 2).

Table C.1 — Example calculation for the cumulation of a two-stage filter system using the typical urban aerosol distribution

d_i in µm	d_{i+1} in µm	$\overline{d}_i$ in µm	$q_{3u}(\overline{d}_i)$	$E_{A,i}$ Filter A in %	$q_{3u}(\overline{d}_i)$ downstream Filter A	$E_{A,i}$ Filter B in %	$E_{\text{cum},i}$ in %	$q_{3u}(\overline{d}_i)$ downstream Filter B
0,30	0,50	0,39	0,221 19	51,5	0,139 35	80,5	90,5	0,044 59
0,50	0,70	0,59	0,219 17	63,5	0,106 30	89,0	96,0	0,020 73
0,70	1,00	0,84	0,165 68	72,7	0,060 47	93,7	98,3	0,006 65
1,00	1,30	1,14	0,115 22	80,0	0,031 51	96,4	99,3	0,002 00
1,30	1,60	1,44	0,085 03	85,0	0,017 01	98,1	99,7	0,000 62
1,60	2,20	1,88	0,076 18	90,0	0,011 43	98,7	99,9	0,000 22
2,20	3,00	2,57	0,080 22	94,7	0,008 06	98,8	99,9	0,000 11
3,00	4,00	3,46	0,099 84	98,1	0,005 29	99,1	100	0,000 06
4,00	5,50	4,69	0,126 88	99,3	0,002 41	99,7	100	0,000 02
5,50	7,00	6,20	0,155 56	100	0,001 09	100	100	0,000 00
7,00	10,00	8,37	0,177 57	100	0,000 00	100	100	0,000 00

NOTE The data above are rounded. Since for the data calculation the actual formulae have been used with more digits than given above, there might be some rounding differences when recalculating the data with the values given above.



Key

X particle size (µm)

Y logarithmic particle distribution density q_{3u}

——— urban distribution (this part of ISO 16890)

▬ ▬ ▬ ▬ downstream filter A

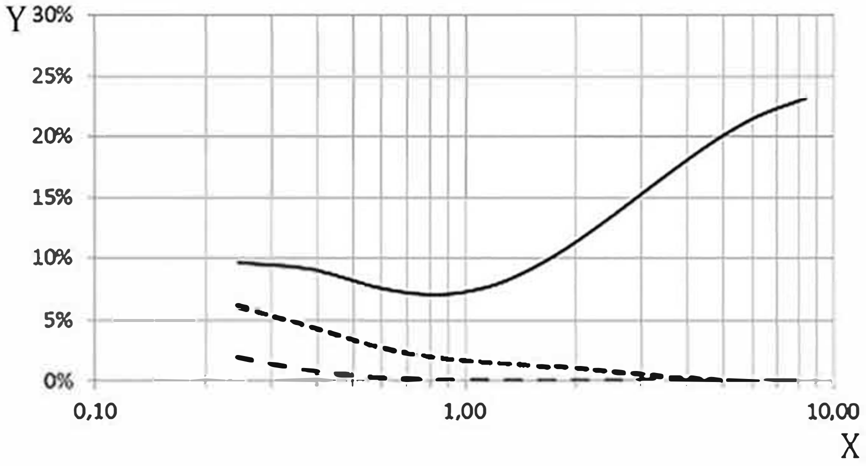
— — — downstream filter B

Figure C.1 — Particle size distribution density of aerosol upstream (urban distribution) and downstream of example Filter A and B using the typical urban aerosol distribution

Table C.2 — Example calculation for the cumulation of a two-stage filter system using the typical rural aerosol distribution

d_i in µm	d_{i+1} in µm	$\bar{d}_i$ in µm	$q_{3r}(\bar{d}_i)$	$E_{A,i}$ Filter A in %	$q_{3r}(\bar{d}_i)$ downstream Filter A	$E_{A,i}$ Filter B in %	$E_{cum,i}$ in %	$q_{3r}(\bar{d}_i)$ downstream Filter B
0,30	0,50	0,39	0,096 51	51,5	0,060 80	80,5	90,5	0,019 46
0,50	0,70	0,59	0,090 88	63,5	0,044 08	89,0	96,0	0,008 59
0,70	1,00	0,84	0,075 71	72,7	0,027 63	93,7	98,3	0,003 04
1,00	1,30	1,14	0,070 14	80,0	0,019 18	96,4	99,3	0,001 22
1,30	1,60	1,44	0,076 28	85,0	0,015 26	98,1	99,7	0,000 56
1,60	2,20	1,88	0,088 38	90,0	0,013 25	98,7	99,9	0,000 25
2,20	3,00	2,57	0,108 04	94,7	0,010 86	98,8	99,9	0,000 15
3,00	4,00	3,46	0,137 26	98,1	0,007 27	99,1	100	0,000 09
4,00	5,50	4,69	0,167 08	99,3	0,003 17	99,7	100	0,000 03
5,50	7,00	6,20	0,195 42	100	0,001 37	100	100	0,000 00
7,00	10,00	8,37	0,216 71	100	0,000 00	100	100	0,000 00

NOTE The data above are rounded. Since for the data calculation the actual formulae have been used with more digits than given above, there might be some rounding differences when recalculating the data with the values given above.



Key

X particle size (µm)
Y logarithmic particle distribution density q_{3r}
——— rural distribution (this part of ISO 16890)
▬ ▬ ▬ downstream filter A
— — — downstream filter B

Figure C.2 — Particle size distribution density of aerosol upstream (rural distribution) and downstream of example Filters A and B using the typical rural aerosol distribution

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