1 SCOPE
This Nordtest method is intended to be used in testing ventilation filters in their normal operating conditions. The purpose of the test is to determine if the fractional efficiency of the filter(s) differs significantly from that expected from the laboratory tests.

2 FIELD OF APPLICATION
The method is primarily intended to be used in the testing of filters used in general ventilation systems. The method can also be applied to any filter which is used in comparable conditions.

3 REFERENCES

4 DEFINITIONS
Aerosol
An assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement.

Aerosol particle
A small discrete object suspended in gaseous media.

Particle size
For spherical particles the size of a particle is defined as the diameter of the spherical object. When using optical particle counter the equivalent PSL (polystyrene latex) particle size is used. This is the particle size indicated by the particle counter calibrated with monodispersed PSL particles.

Aerodynamic particle size is an equivalent particle size defined as a diameter of a unit density sphere having the same aerodynamic properties as the particle in question. Aerodynamic particle size is used e.g. when measuring the particle size distribution with a cascade impactor.

Particle concentration
The number of particles in a specified volume of air. Particle number concentration is defined as the number of particles in a unit volume of air. Number concentration is typically used e.g. when making measurements with an optical particle counter.

Particle mass concentration is defined as the particle mass in unit volume of air. Mass concentration is normally used when measuring particle concentration with filter sample or gravimetric method.

Particle size distribution
A relationship expressing the quantity of a particle property (number or mass) associated with particles in a given size range. An optical particle size analyzer is typically used to measure particle number size distribution while a cascade impactor is used when particle mass size distribution is to be measured.
Filter efficiency
Filter efficiency or removal efficiency is expressed in terms of an efficiency of collection, i.e. the fraction of entering particles that is retained by the filter. Filter efficiency \( E \) can be calculated by

\[
E = 100 \left( 1 - \frac{c_b}{c_a} \right)
\]

where \( c_a \) and \( c_b \) refer to the concentration of particles entering and leaving the filter.

Filter Penetration
Filter penetration is given by

\[
P = 100 \left( \frac{c_b}{c_a} \right)
\]

Flow rate
Filter flow rate \( qV \) is the volumetric flow through the filter.

Pressure drop
Pressure drop is the pressure difference across the filter caused by the filter material’s resistance to air flowing through it.

5 SAMPLING
A single ventilation filter or filter installation must be tested in normal operation conditions.

6 METHOD OF TEST
6.1 Principle
The basic principles of the test method are presented in EUROVENT 4/10 (Anon. 1996). This test method includes additional instructions for the use of a reference filter method and some other details which improve the conditions for making filter efficiency measurements in ambient air conditions.

The purpose of the test method is to determine the fractional efficiency or penetration of a ventilation filter or filter installation in normal operating conditions. This is accomplished by measuring the upstream and downstream particle size distributions with an optical particle counter or other size selective measuring instrument which is shown to provide reliable results in ambient air conditions. The measured particle concentrations corresponding to certain particle size values are used to calculate filter efficiency \( E \) or filter penetration \( P \).

The filter test is made by using ambient air particles. This may cause significant errors in particle sizing. A reference filter with known filtration characteristics is therefore used to check if the measurement conditions are favorable enough for a reliable filter test. The reference filter method is also used to make a field calibration of the particle counter in such a way that the effect of inaccurate particle sizing can be reduced.

6.2 Apparatus
6.2.1 Basic principles
The basic principle of the test system is illustrated in Figure 1. This system includes:

- sampling probes
- sampling tubes
- valves
- virtual impactor & pump
- particle counter.

The diameters of the upstream and downstream sampling probes are chosen in such a way that isokinetic conditions can be assumed to prevail. Sampling lines should be constructed in such a way that particle losses can be minimized. This may be difficult in many of the test locations. Especially, if the overall efficiency of a large filter installation is tested, the downstream sampling location should be far from the filter to ensure effective air mixing.

Sampling probes are installed in such a way that representative values of particle concentrations can be measured from both sides of the filter. If the efficiency of a filter is to be measured, the downstream sampling point is located no closer than 0.5 m from the back side of the filter. If the overall efficiency of the filtration system is to be tested, the downstream sampling point must be placed far enough to guarantee effective air mixing between the filter and sampling point.

Sampling probes are connected to the particle measurement system by sampling tubes. Sampling tubes must be made of anti-static material and they must be kept as short as possible to minimize particle losses. All sampling lines should be as identical as possible, i.e. tube lengths and the radii of the bends should be identical. If long sampling tubes with several bends are used, the similar sampling system must be tested in a laboratory to determine the influence of particle losses.
Manually or automatically operated ball valves with large aperture should be used to switch between upstream and downstream sampling lines. The present system includes an optional virtual impactor which can be used to increase the concentration of large particles. This is of great importance if the test method is used to check the influence of air leaks. The virtual impactor is operated with a pump which also guarantees an adequate sample flow through the sampling lines.

Filter measurements must be made at the concentration level which is within the limits of the particle counter. A proper dilution system must be used if the particle concentration exceeds the upper concentration limit of the particle counter. The procedures of aerosol dilution are presented in EUROVENT 4/10.

The measurement system shown in Figure 1 is used to measure the efficiency or penetration of the test filter(s) and a reference filter the properties of which are accurately known from controlled laboratory measurements. The reference filter should be chosen in such a way that its penetration curve can be assumed to be very close to that of the test filter. The filtration properties (fractional efficiency and/or penetration) of the reference filter are measured in controlled laboratory conditions by using the methods described in prEN779.

6.2.2 Modification 1

The measurement system shown in Figure 1 can be used to measure the efficiency of the test filter and reference filter. It is, however, important that the efficiencies of test filter and reference filter are measured as simultaneously as possible. The test should therefore preferably be made with a system illustrated in Figure 2. This system includes three sampling lines, i.e. an additional sampling line and valve for the reference filter. This arrangement makes it possible to measure both filters almost simultaneously.

6.2.3 Modification 2

Filter properties can also be measured with two identical particle counters (Figure 3). The advantage of this method is that sampling can be made with short sampling tubes. The upstream particle counter (#1) is used to measure the concentration of unfiltered air and the air downstream of the reference filter. Thus, the efficiency of the reference filter is measured with the aid of the valve system. The efficiency of the test filter is determined from the results provided by the upstream particle counter #1 (unfiltered air) and the downstream particle counter #2 (filtered air). The main advantage of this method is the simultaneous measurement of upstream and downstream concentrations. It also allows downstream particle sampling far from the filter which is very important if the influence of air leaks is tested.

It must be emphasized that the particle counters must be exactly identical which may require very careful calibration of the instruments. If two particle counters are used in filter efficiency measurements, a test series is required to show that the system produces efficiency values which are in accordance with those measured with a particle counter equipped with valve sampling system.

6.3 Procedure

6.3.1 Basic steps

The test procedure includes practically the same steps as those described in EUROVENT 4/10, i.e.

- air flow of the filter(s) shall be either estimated or measured with a proper air velocity meter (e.g. thermal anemometer)
- humidity and air temperature inside the ventilation system are measured and recorded
- filter pressure drop (static pressure) is measured with a micromanometer
- fractional efficiency of the test filter and the reference filter is measured as described below.

In addition to these steps the checklist according to EUROVENT 4/10 should also be followed, i.e.
air temperature and humidity in the air surrounding the measuring instruments are measured and recorded (values must be within the range specified for the instruments)

the particle concentration level is checked to ensure that measurements are made within the operational range of the particle counter – if necessary, a proper aerosol diluter is used

the tightness of the measurement system is tested with the aid of HEPA filters in both sampling lines.

6.3.2 Sampling cycles – basic procedure

The aerosol sampling system shown in Figure 1 is used to measure particle concentrations alternately from upstream and downstream of the test filter. Next, the same procedure is used to measure particle concentrations from both sides of the reference filter. Thus, the measurement of the efficiency of the test filter and the reference filter does not take place simultaneously. This may cause significant inaccuracy if measurement conditions vary strongly with time.

The particle counting cycle in these measurements is defined in prEN779. The timing of the measurement is shown in Table 1. This timing must be applied separately to the test filter and the reference filter, i.e. two separate efficiency tests are made.

6.3.3 Sampling cycles – Modification 1

The aerosol sampling system shown in Figure 2 is used to measure particle concentrations alternately from upstream and downstream of the test filter and reference filter. The particle counting cycles are as described in prEN779. The timing of the measurement is shown in Table 2. The measurement of the efficiencies of test filter and the reference filter takes place almost simultaneously, i.e. effects of varying measurement conditions can be significantly reduced.

6.3.4 Sampling cycles – Modification 2

The timing of the measurement is shown in Table 3.

---

Table 1. Measurement cycles: measurement with an optical particle counter equipped with two valves.

<table>
<thead>
<tr>
<th>Measurement Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>N_u,1</td>
<td>N_u,2</td>
<td>N_u,3</td>
<td>N_u,4</td>
<td>N_u,5</td>
<td>N_u,6</td>
<td>N_u,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>N_d,1</td>
<td>N_d,2</td>
<td>N_d,3</td>
<td>N_d,4</td>
<td>N_d,5</td>
<td>N_d,6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Measurement cycles: measurement with an particle counter equipped with three valves.

<table>
<thead>
<tr>
<th>Measurement Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>N_u,1</td>
<td>N_u,2</td>
<td>N_u,3</td>
<td>N_u,4</td>
<td>N_u,5</td>
<td>N_u,6</td>
<td>N_u,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>N_d,1</td>
<td>N_d,2</td>
<td>N_d,3</td>
<td>N_d,4</td>
<td>N_d,5</td>
<td>N_d,6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>N_r,1</td>
<td>N_r,2</td>
<td>N_r,3</td>
<td>N_r,4</td>
<td>N_r,5</td>
<td>N_r,6</td>
<td>N_r,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Measurement cycles: measurement with two particle counters equipped with two valves.

<table>
<thead>
<tr>
<th>Measurement Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<th>10</th>
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<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>N_u,1</td>
<td>N_u,2</td>
<td>N_u,3</td>
<td>N_u,4</td>
<td>N_u,5</td>
<td>N_u,6</td>
<td>N_u,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>N_r,1</td>
<td>N_r,2</td>
<td>N_r,3</td>
<td>N_r,4</td>
<td>N_r,5</td>
<td>N_r,6</td>
<td>N_r,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>N_d,1</td>
<td>N_d,2</td>
<td>N_d,3</td>
<td>N_d,4</td>
<td>N_d,5</td>
<td>N_d,6</td>
<td>N_d,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4 Handling of the test results.

6.4.1 Fractional penetration

Fractional penetration $P_i$, i.e. penetration corresponding to a certain size channel of the particle counter is given by

$$P_i = \frac{N_{d,i}}{(N_{u,i} + N_{u,i+1})/2}$$  \hspace{1cm} (3)

where $N_{d,i}$ refers to the $i$th downstream particle count while $N_{u,i}$ and $N_{u,i+1}$ refer to the corresponding upstream particle counts measured right before and right after the downstream measurement. This technique is used to minimize the effects of varying upstream particle concentrations during the efficiency measurement. Equation (3) corresponds to the conventional efficiency measurement with a two-valve sampling system.

When measuring particles from the storage chambers, fractional penetration is given by

$$P_i = \frac{N_{d,i}}{N_{u,i}}$$  \hspace{1cm} (4)

where $N_{d,i}$ refers to the $i$th downstream particle count while $N_{u,i}$ refers to the corresponding particle count measured from the upstream storage chamber. This equation is also used when filters are tested with two optical particle counters.

The corresponding equation for three-valve sampling system is given by

$$P_i = \frac{N_{d,i}}{(N_{u,2i-1} + N_{u,2i})/2}$$  \hspace{1cm} (5)

where $N_{d,i}$ refers to the $i$th downstream particle count while $N_{u,2i-1}$ and $N_{u,2i}$ refer to the corresponding upstream particle counts measured right before and right after the downstream measurement.

The corresponding equation for the Penetration of the reference filter is

$$P_{ref,j} = \frac{N_{d,j}}{(N_{u,2j-1} + N_{u,2j})/2}$$  \hspace{1cm} (6)

where $N_{d,j}$ refers to the $i$th downstream particle count and $N_{u,2j-1}$ and $N_{u,2j}$ to the upstream particle counts, respectively.

The fractional penetration $P_{ave}$ is the average of the individual penetration values, i.e.

$$P_{ave} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} P_i \hspace{1cm} (n = 6)$$  \hspace{1cm} (7)

This equation is used for both filters, i.e. average penetration values are calculated separately for the test filter and the reference filter.

The uncertainty $\Delta P$ of the average fractional penetration is calculated using the same principle as in EUROVENT 4/10 and prEN 779, i.e.

$$\Delta P = k_n \frac{\delta}{\sqrt{n}}$$  \hspace{1cm} (8)

where $k_n$ refers to the factor the value of which depends on the degree of freedom and the confidence level (see e.g. ISO 2854-1976). At the 95% confidence level the following values are used $k_4 = 2.35$, $k_5 = 2.13$, $k_6 = 2.02$, $k_7 = 1.94$, $k_8 = 1.90$, $k_9 = 1.86$, $k_{10} = 1.83$, $k_{11} = 1.81$ and $k_{12} = 1.80$.

Standard deviation $\delta$ is given by

$$\delta = k_n \sqrt{\frac{\sum_{i=1}^{n} (P_i - P_{ave})^2}{n - 1}}$$  \hspace{1cm} (9)

Thus, the final result is expressed in the form

$$P = P_{ave} \pm \Delta P$$  \hspace{1cm} (10)

6.4.2 Determination of equivalent penetration

The experimental penetration values are used to determine corresponding equivalent penetration values. Figure 4 illustrates the principle of the procedure which is based on the calibration curve, i.e. the penetration curve of the reference filter measured in controlled laboratory conditions. The penetration of the reference filter measured with ambient air particles is compared with the calibration curve. This comparison is used to determine a corrected particle size for each size channel of the particle counter. The corrected particle size is equal to the particle size corresponding the same penetration value on the calibration curve. The similar particle size correction is then made for the test filter data. This correction procedure is actually a field calibration method which is used to reduce the inaccuracy caused by inaccurate particle sizing.

![Figure 4. Correction procedure for filter penetration measurement.](image)

6.5 Expression of results

6.5.1 Filtration system

The following information on the filtration system results should be given:

- description of the ventilation system (location, traffic conditions, major particle sources)
- weather conditions
- schematic drawing of the air filtration system
- number of filters
• type of filters
• age of filters
• location of the sampling points
• other comments.

6.5.2 Air data
The information dealing with the properties of the air entering the filter(s) should include:
• air flow
• pressure drop
• relative humidity
• temperature.

6.5.3 Measurement instruments
The instruments used in the filter test must be reported as follows:
• properties of particle counter(s)
• calibration data of the particle counter(s)
• description of the dilution system
• description of the aerosol concentrator (virtual impactor)
• description of the sampling system (sampling probes, sampling tubes, valves, storage chambers)
• reference filter(s)
• sample flow rate(s).

6.5.4 Fractional penetration
Test results should include:
• penetration values for each size channel of the optical particle counter
• uncertainty of the penetration values for each size channel of the optical particle counter
• corrected particle sizes for each size channel.

The results shall also include the penetration values of the reference filter as measured under controlled laboratory conditions. The corrected test result shall include the measured penetration values and the particle size values determined from the calibration curve of the reference filter. The results must also include the calculated uncertainties.

Table 4. Example of measurement results.

<table>
<thead>
<tr>
<th>Channel boundaries (µm)</th>
<th>Channel midpoint (µm)</th>
<th>P (%)</th>
<th>∆P (%)</th>
<th>P 1 (%)</th>
<th>P 2 (%)</th>
<th>P 3 (%)</th>
<th>P 4 (%)</th>
<th>P 5 (%)</th>
<th>P 6 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 - 0.5</td>
<td>0.39</td>
<td>50.57</td>
<td>1.644</td>
<td>52.22</td>
<td>49.69</td>
<td>48.30</td>
<td>51.15</td>
<td>53.32</td>
<td>48.75</td>
</tr>
<tr>
<td>0.5 - 0.7</td>
<td>0.59</td>
<td>29.95</td>
<td>2.033</td>
<td>27.88</td>
<td>28.23</td>
<td>29.98</td>
<td>34.71</td>
<td>29.48</td>
<td>29.42</td>
</tr>
<tr>
<td>0.7 - 1</td>
<td>0.84</td>
<td>19.31</td>
<td>1.913</td>
<td>17.28</td>
<td>15.88</td>
<td>19.76</td>
<td>19.92</td>
<td>20.88</td>
<td></td>
</tr>
<tr>
<td>1 - 2</td>
<td>1.41</td>
<td>9.79</td>
<td>1.849</td>
<td>11.35</td>
<td>8.33</td>
<td>7.84</td>
<td>7.23</td>
<td>12.53</td>
<td>11.45</td>
</tr>
<tr>
<td>2 - 5</td>
<td>3.16</td>
<td>2.73</td>
<td>1.874</td>
<td>3.03</td>
<td>2.76</td>
<td>1.94</td>
<td>2.30</td>
<td>6.20</td>
<td>1.45</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>7.07</td>
<td>2.95</td>
<td>1.394</td>
<td>3.03</td>
<td>2.76</td>
<td>1.94</td>
<td>2.30</td>
<td>6.20</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Reference filter:

<table>
<thead>
<tr>
<th>Channel boundaries (µm)</th>
<th>Channel midpoint (µm)</th>
<th>P (%)</th>
<th>∆P (%)</th>
<th>P 1 (%)</th>
<th>P 2 (%)</th>
<th>P 3 (%)</th>
<th>P 4 (%)</th>
<th>P 5 (%)</th>
<th>P 6 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 - 0.5</td>
<td>0.39</td>
<td>44.81</td>
<td>1.651</td>
<td>40.86</td>
<td>45.88</td>
<td>45.33</td>
<td>46.21</td>
<td>45.83</td>
<td>44.77</td>
</tr>
<tr>
<td>0.5 - 0.7</td>
<td>0.59</td>
<td>24.92</td>
<td>1.791</td>
<td>20.93</td>
<td>25.48</td>
<td>26.20</td>
<td>25.27</td>
<td>24.39</td>
<td>27.23</td>
</tr>
<tr>
<td>0.7 - 1</td>
<td>0.84</td>
<td>14.49</td>
<td>1.718</td>
<td>15.16</td>
<td>13.29</td>
<td>11.18</td>
<td>17.00</td>
<td>14.23</td>
<td>16.06</td>
</tr>
<tr>
<td>1 - 2</td>
<td>1.41</td>
<td>6.50</td>
<td>1.358</td>
<td>4.35</td>
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<td>0.04</td>
<td>0.00</td>
<td>1.71</td>
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<tr>
<td>&gt; 5</td>
<td>7.07</td>
<td>0.00</td>
<td>0.000</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
</tbody>
</table>

Table 5. Results of the correction procedure.

<table>
<thead>
<tr>
<th>Channel boundaries (µm)</th>
<th>Channel midpoint (µm)</th>
<th>Test filter</th>
<th>Reference filter</th>
<th>Corrected particle size (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 - 0.5</td>
<td>0.39</td>
<td>50.57</td>
<td>1.64</td>
<td>44.81</td>
</tr>
<tr>
<td>0.5 - 0.7</td>
<td>0.59</td>
<td>29.95</td>
<td>2.03</td>
<td>24.92</td>
</tr>
<tr>
<td>0.7 - 1</td>
<td>0.84</td>
<td>19.31</td>
<td>1.91</td>
<td>14.49</td>
</tr>
<tr>
<td>1 - 2</td>
<td>1.41</td>
<td>9.79</td>
<td>1.85</td>
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</tr>
<tr>
<td>2 - 5</td>
<td>3.16</td>
<td>2.73</td>
<td>1.87</td>
<td>0.53</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>7.07</td>
<td>2.95</td>
<td>1.39</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Model_Result.xls, 16.06.2000
Figure 5 illustrates an example of how to present the uncorrected and corrected penetration values in a single graph.

![Graph of penetration values](image)

**Figure 5. Example of graphical presentation of the measurement results.**

### 6.6 Accuracy

The accuracy of the filter test in field conditions is difficult to define. The general principle is, however, that the uncertainty of the measurement should be in the range of 1–5%.

### 6.7 Test report

The test report should include the following information:

a) Name and address of the testing laboratory

b) Identification number of the test report

c) Name and address of the organization or the person who ordered the test

d) Purpose of the test

e) Description of the ventilation system

f) Name and address of the manufacturer of the filter(s)

g) Name or other identification marks of the tested filter(s)

h) Date of the test

i) Test method

j) Conditioning of the test specimens, environmental data during the test (temperature, pressure, RH, etc.)

k) Identification of the test equipment and instruments used

l) Any deviation from the test method

m) Test results

n) Inaccuracy or uncertainty of the test result

o) Date and signature.