ROOM AIR CLEANERS; PORTABLE:
PERFORMANCE

Key words: Room air cleaners, performance

1. SCOPE AND FIELD OF APPLICATION

This Nordtest method is used to test technical performance of portable room air cleaners, to control tobacco particles in indoor air.

The method measures the relative reduction by the air cleaner of particulate matter suspended in the air in a specified test chamber.

The method contains tests for the following:
1) Power consumption of the air cleaner.
2) Air volume flow through the air cleaner.
3) Effective cleaning rate (ECR) calculated as the flow rate of particle-free air required to produce the observed decay rate in cigarette smoke.
4) System efficiency (SE) calculated as the observed effective cleaning rate (ECR) divided by the measured air flow rate.
5) Effective cleaning rate ratio (ECRR) calculated as the observed effective cleaning rate (ECR) divided by the air cleaner’s power consumption.
6) Calculated cleaning time (CCT 5%) to reduce the initial concentration of particles from 100 % down to 5 % with reference to 50 m³ test chamber.
7) Instructive measurement of ozone (O₃) production.

The sound level of the air cleaner is not measured. The user is often in a better position to evaluate whether the sound level is acceptable or not. It is, on the other hand, much harder for the user to evaluate how effectively the air cleaner cleans the air of tobacco particles.

The size of air cleaners is limited to 500 m³/h through the air cleaner, with reference to a 50 m³ test chamber.

2. REFERENCE

The method is based on the following documents.

NVG: “Metoder för mätning av luftflöden i ventilationsinstallationer” (Methods for measurement of air flows in ventilation installations), 1982.

3. DEFINITIONS

- Portable room air cleaner

An appliance, with the function of removing particulate matter from the air, which can be moved from room to room.

- Types of portable room air cleaners

Fan with filter

Air cleaner which operates with a source of electric power and contains a motor and fan to draw air through a filter or filter(s).

Fan with filter and electrostatic plates

Air cleaner which incorporates electrically charged plates to attract particulate matter in addition to a fan with filter(s).

Fan filter with negative ion generator

Air cleaner which incorporates a negative ion generator in addition to a fan and filter(s).

Negative ion generator

Air cleaner which incorporates only a negative ion generator.

Other types

Devices which have the stated capability to reduce the concentration of particulate matter in a room.

- Test particulate matter

Cigarette smoke

Smoke produced by Danish Red Prince tobacco (as default), burning naturally (non-forced). Other tobacco brands which bear a fair comparison with Danish Red Prince are acceptable.

Test Chamber

The room-size chamber for determining performance in removing particulate matter from the air. (The specifications for the Nordtest chamber are shown in Appendix 4).
Circulating fan
A fan (25 Watt) used to mix the air in the chamber.

Particulate matter removal
The reduction of particle number concentration in air due solely to the operation of the air cleaner.

High efficiency particulate air (HEPA) filter
An air filter with a rate greater than or equal to 99.9% removal of diocetyl phthalate of 0.3 (µm) diameter.

Particle number concentration
Number of particles per unit volume of room air (particles/cm³).

Natural decay
The reduction of particulate matter due to the natural phenomena in the test chamber, principally sedimentation, agglomeration and surface deposition.

Air cleaner power consumption
The measured input power to the air cleaner when it is operating (Watt).

Volume flow
The amount of air flowing through the air cleaner, expressed in cubic metres per hour (m³/h).

Effective cleaning rate (ECR)
Calculated as the flow rate of particle-free air required to produce the observed decay rate in cigarette smoke expressed in cubic metres per hour (m³/h). See Appendices 1, 2 and 3 for ECR calculation.

System efficiency (SE)
System efficiency is calculated as the observed effective cleaning rate (ECR) divided by measured air flow rate. SE is expressed in percent (%).

Effective cleaning rate ratio (ECRR)
Effective cleaning rate ratio is calculated as the observed effective cleaning rate (ECR) divided by the air cleaner’s power consumption. ECRR is expressed in (m³/h/Watt).

Calculated cleaning time (CCT 5%)
The calculated cleaning time is based on the slope of the regression line calculated in the ECR-value. It is the time for an air cleaner to reduce the initial concentration of particles from 100 % down to 5 % with reference to a 50 m³ test chamber expressed in (hours).

Ozone production
Ozone production refers to the amount of ozone generated by an electric air cleaner in standard test chamber conditions. This production is expressed in mg per hour (mg/h).

5. SAMPLING
If the air cleaner is in serial production it must be tested with all its accessories and accompanying documents in the same way as it is normally available to a consumer.

6. TEST METHOD
In this method, we discuss an in situ measurement technique for evaluating the performance of portable air cleaners.

Air cleaning performance parameters
Currently there are no standard methods for testing or rating portable air cleaners for tobacco smoke. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has a standard testing procedure (ASHRAE, 1976) for evaluating ducted air cleaning devices, but its present form is not applicable to the evaluation of unducted devices. Furthermore, the ASHRAE test for arrestance and dust-spot efficiency does not give specific information regarding the efficiency of removing respirable size particles. In order to evaluate the effect of ion-generators on particle removal, it is necessary to conduct an in situ test without the aid of mixing fans since these devices normally rely on natural air movement to transport charged particles to surfaces in the room. Several researchers have used in situ measurement techniques which are appropriate for evaluating the performance of portable air cleaning devices. The test procedure normally involves filling a room-size chamber with a contaminant, mixing the air to obtain a uniform initial concentration, and measuring the contaminant decay rate with and without the air cleaner operating. The increase in the contaminant decay rate observed with the device operating is used to calculate the air cleaning rate of the device. If the flow rate of air through the device is known, a system efficiency may be calculated.

If an air cleaner is operating in a chamber of volume V and there is no significant internal source of particles, and the rate at which outdoor particles infiltrate into the chamber is negligible, then the following differential mass balance equation describes the decay rate of the average particle concentration C, within the chamber:

\[
\frac{dC}{dt} = - \frac{q_v C_{ex}}{V} - KC - \frac{q_d (C_{into} - C_{out})}{V}
\]

where
- \(q_v\) = the flow rate of ventilation air (infiltration and mechanical ventilation);
- \(C_{ex}\) = the concentration of particles in the outgoing ventilation air;
- \(K\) = a constant that accounts for removal of particles by mechanisms other than ventilation (e.g. surface deposition);
- \(q_d\) = the flow rate of air through the air cleaning device
- \(C_{into}\) = the concentration of particles in the air entering the air cleaner, and
- \(C_{out}\) = the concentration of particles in the air leaving the air cleaner.
Three parameters calculated from our data are the effective cleaning rate (ECR), the system efficiency (SE) and the calculated cleaning time (CCT 5%) to reduce the initial concentration of particles from 100% down to 5% with reference to a 50 m³ test chamber. The ECR is the difference in the observed particle decay rates with and without the air cleaner operating, multiplied by the chamber volume. This calculation yields an air flow rate that represents the effective amount of particle-free air produced by the air cleaner. The ECR is particularly useful in estimating the effects of the device in various size rooms or in comparing air cleaning to ventilation as an indoor air quality control technique. The system efficiency (SE) is the ECR divided by the actual air flow rate through the air cleaner.

The previous expressions relate the performance of the air cleaner to the decay rate of the average indoor particle concentration. One difficulty with this approach is that it requires an accurate measurement of the average concentration within the enclosure. A common means of monitoring the average concentration is to mix the chamber air vigorously with fans during the test. A problem with this technique is that it can improve the performance of devices such as ion-generators which rely on natural air movement to transport particles. Mixing also obscures air cleaner inefficiencies resulting from short-circuiting. Another technique which may be employed is to use an elaborate multi-point sampling manifold. However, the complexity of such a probe makes this an unattractive and cumbersome option. We note, however, that it is not necessary to measure the average concentration to determine the decay rate of the average concentration. Sandberg (1981) and others have shown mathematically and experimentally that with imperfect mixing of indoor air and an initially uniform pollutant concentration, the decay rate initially varies from location to location depending on the distribution pattern of clean air, but eventually the decay rates at all locations become equal. Thus, this equilibrium decay rate measured at any location will equal the decay rate in average concentration and can be used to characterise the performance of an air cleaner. From our experiences with chamber decays without mixing fan, the equilibrium decay rate is established quite quickly.

6.1 Apparatus

<table>
<thead>
<tr>
<th>Measured parameters</th>
<th>Measuring apparatus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test chamber temperature</td>
<td>(T °C ± 0.2 °C). Example Brüel &amp; Kjær Type 1213</td>
</tr>
<tr>
<td>Test chamber humidity</td>
<td>(RH% ± 2.0). Example Bruel &amp; Kjær Type 1213</td>
</tr>
<tr>
<td>Power consumption</td>
<td>(0-100 W range ± 1 Watt 0-200 W range ± 2 Watt)</td>
</tr>
<tr>
<td>Volume flow</td>
<td>Duct air velocity (0-5 m/s ± 0.02 m/s). Example: Alnor GGA 65 P</td>
</tr>
<tr>
<td>Effective cleaning rate (ECR)</td>
<td>Particle counter: Example: PMS-model, LAS-X CRT (0.1 to 7.5 µm), or TSI 3030 Electrical Aerosol Analyzer (0.01 to 1.0 µm).¹</td>
</tr>
<tr>
<td>Ozone gas production</td>
<td>Example: Dräger Tube Ozone and Dräger Multi Gas Detector Model 31, Standard range: (0.05-0.7 ppm) also 0.1-1.4 ppm or 0.005-0.07 ppm. St.D. = ± 10 %</td>
</tr>
</tbody>
</table>

¹ According to Ref. 2 the use of either LAS-X or TSI will give approx. same results.

6.2 Preparation of test samples

The apparatus is tested in the condition as specified in the instruction to the consumer. The proper condition and correct operation of the apparatus are checked. The apparatus is then photographed.

6.3 Procedure

6.3.1 Power consumption

The power consumption is measured at each speed setting using an AC watt meter.

6.3.2 Volume flow

The volume flow is measured at each speed setting using the following procedure as shown in Figures 1 and 2:

The figures show the measuring principle used for volume flow measurement.

\[ D_h = 2 \cdot L_1 \cdot L_2/(L_1 + L_2) \]

where \( L_1 \) and \( L_2 \) are the lengths of the sides of the rectangle.

\( v_0 \) is a measured speed in the inlet of the air cleaner. It may be necessary to measure the air speed at several places in the inlet to get an acceptable value for \( v_0 \). \( v_0 \) is measured before and after mounting the measuring duct, in the outlet opening. \( <V_{ch}> \) is the medium speed in the measuring duct, and is measured in accordance with (NVG), see figure below. For \( L_1 \) less than 0.2 m, \( 0.2 < L_1, < 0.4 \) is used.

Particle generation

Experiments were conducted using tobacco smoke as a source of particles because (1) it is one of the most prevalent indoor particle sources, (2) it is easily generated and (3) it provides a polydisperse aerosol with a repeatable size distribution spanning the whole size range of respirable particles. Tobacco smoke is also an indoor contaminant for which most manufacturers of portable air cleaners have made performance claims.
According to new standard for ducts, SIS 82 72 04.

Two dim. ranges for $L_2$:  
I  $200 < L_2 \leq 300$  
II  $400 < L_2 \leq 2000$

For range I:  
$$a = 0.08 \cdot L_2, \quad b = 0.43 \cdot L_2, \quad c = 0.57 \cdot L_2, \quad d = 0.92 \cdot L_2$$

For range II:  
$$a = 0.060 \cdot L_2, \quad b = 0.235 \cdot L_2, \quad c = 0.430 \cdot L_2, \quad d = 0.570 \cdot L_2$$
$$e = 0.765 \cdot L_2, \quad f = 0.940 \cdot L_2$$

Three measuring cases for $L_1$:

The placing of measuring points for cases 1, 2 and 3 is then as follows:

<table>
<thead>
<tr>
<th>$L_2$</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>16</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>85</td>
<td>95</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>b</td>
<td>85</td>
<td>110</td>
<td>130</td>
<td>90</td>
<td>120</td>
<td>140</td>
<td>190</td>
<td>235</td>
<td>280</td>
<td>330</td>
<td>375</td>
<td>420</td>
<td>470</td>
</tr>
<tr>
<td>c</td>
<td>115</td>
<td>140</td>
<td>170</td>
<td>170</td>
<td>215</td>
<td>260</td>
<td>345</td>
<td>430</td>
<td>515</td>
<td>600</td>
<td>690</td>
<td>775</td>
<td>860</td>
</tr>
<tr>
<td>d</td>
<td>184</td>
<td>230</td>
<td>275</td>
<td>230</td>
<td>285</td>
<td>340</td>
<td>455</td>
<td>570</td>
<td>685</td>
<td>800</td>
<td>910</td>
<td>1025</td>
<td>1140</td>
</tr>
<tr>
<td>e</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>305</td>
<td>380</td>
<td>460</td>
<td>610</td>
<td>765</td>
<td>920</td>
<td>1070</td>
<td>1225</td>
<td>1380</td>
<td>1530</td>
</tr>
<tr>
<td>f</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>380</td>
<td>470</td>
<td>585</td>
<td>750</td>
<td>940</td>
<td>1130</td>
<td>1315</td>
<td>1505</td>
<td>1690</td>
<td>1880</td>
</tr>
</tbody>
</table>
The volume flow can then be calculated by using the following formula:

\[ Q = \frac{V_0}{V_1} \cdot \langle v_{ch} \rangle \cdot \text{Area}_{ch} \cdot 3600 \text{ (m}^3\text{/h)} \]

6.3.3 Effective cleaning rate (ECR)

The air cleaner should be conditioned and run to full satisfaction before testing.

To determine the performance on cigarette smoke, carry out the test procedures prescribed in Sections 6.3.3a and 6.3.3b sequentially during the same day.

6.3.3a Natural decay measurement

Place the air cleaner to be tested on the table in the centre of the chamber and set the air cleaner controls to the conditions for test. Test for proper operation, then turn off with switch external to test chamber.

Operate the circulating fan and identify a log sheet file for the run.

Using HEPA filter, allow the test chamber air to clean until the background concentration of particles is almost constant, for example total measured number less than 100 particles/cm\(^3\) (0.1-7.5 µm).

When a suitable background particulate matter level is reached, record the background concentration, turn off the HEPA filter. Light a cigarette outside the chamber, open the door carefully as little as possible, go slowly into the chamber and place the cigarette in the ash tray. Go slowly out again and close the door quickly. The burning time for the cigarette is approximately 15 minutes (Danish Red Prince). Open the door carefully as little as possible. Go slowly into the chamber and remove the cigarette and ash tray. Go slowly out again and close the door quickly. Turn on the four circulation fans for 5 minutes and then switch them off.

Wait 2 minutes for the circulating fans to stop. Begin to acquire the particle concentration with the optical particle counter. This test point is the initial chamber concentration \((t = 0)\).

Acquire particle concentration data at 2 minute intervals as default. A minimum of 10 data points with particle concentrations greater than the lower limit of instrument measurability are required.

It is very important to be aware of the transient path at the beginning of the registration period, which can not be designated as exponentially decreasing.

Record the average RH and temperature of the chamber during the test period. Due to the hygroscopic nature of cigarette smoke, the relative humidity of the test chamber shall be prescribed to 40 RH% ± 10 and temperature 20 ± 3 °C.

Calculate the decay constant for cigarette smoke per Appendix 1.

Determine the acceptability of the run by calculating the coefficient of determination and the standard deviation of the natural decay in accordance with Appendix 2. A coefficient of determination greater than 0.98 and a standard deviation less than the 95% confidence limits of 3 m\(^3\)/h to determine the acceptability of the run.

6.3.3b Particulate matter removal measurement

Operate the circulating fan and identify a log sheet file for the run.

Using HEPA filter, allow the test chamber air to clean until the background concentration of particles is almost constant, for example total measured number less than 100 particles/cm\(^3\) (0.1-7.5 µm).

When a suitable background particulate matter level is reached, record the background concentration, turn off the HEPA filter. Light a cigarette outside the chamber, open the door carefully as little as possible, go slowly into the chamber and place the cigarette in the ash tray. Go slowly out again and close the door quickly. The burning time for the cigarette is approximately 15 minutes (Danish Red Prince). Open the door carefully as little as possible. Go slowly into the chamber and remove the cigarette and ash tray. Go slowly out again and close the door quickly. Turn on the four circulation fans for 5 minutes and then switch them off.

Wait 2 minutes for the circulating fan to stop. Begin to acquire the particle concentration with the optical particle counter.

Turn on the air cleaner.

This test point is the initial chamber concentration \((t = 0)\).

Acquire particle concentration data at 2 minute intervals as default. A minimum of 10 data points with particle concentrations greater than the lower limit of instrument measurability are required. Depending on the air cleaner size (and cleaning efficiency), it may be necessary to increase/decrease the sampling interval, but be careful to check that the particle counter has sufficient data storage to handle the changed sampling interval.

It is very important to be aware of the transient path at the beginning of the registration period, which can not be designated as exponentially decreasing.

Record the average RH and temperature of the chamber during the test period. Due to the hygroscopic nature of cigarette smoke, the relative humidity of the test chamber shall be prescribed to 40 RH% ± 10 and temperature 20 ± 3 °C.

Turn off the air cleaner.

Calculate the decay constant for cigarette smoke in accordance with Appendix 1.
Determine the acceptability of the run by calculating the coefficient of determination and the standard deviation of the natural decay particulate matter removal in accordance with Appendix 2. A coefficient of determination greater than 0.98 and a standard deviation of less than 95% confidence limit of 13 m³/h or 10%, whichever is greater, determines the acceptability of the run.

Determine the ECR of the air cleaner in accordance with Appendix 3.

Determine the acceptability of the test by calculating an estimate of the standard deviation for a single test ECR according to Appendix 3. A two standard deviation estimate of less than 9 ECR or 10%, whichever is greater, determines an acceptable test.

6.3.4 Calculation of system efficiency (SE)

The system efficiency is the ECR divided by the actual air flow rate through the air stream.

\[ SE = \frac{ECR}{q_v} \times 100 \, (\%) \]

6.3.5 Calculation of the effective cleaning rate ratio (ECRR)

The effective cleaning rate ratio is the ECR divided by the power consumption:

\[ ECRR = \frac{ECR}{P} \, (m^3/h/Watt) \]

6.3.6 Calculation of the cleaning time \((CCT_{5\%})\)

The calculated cleaning time to reduce the particle concentration from 100% down to 5% with reference to 50 m³ test chamber is:

\[ C = C_0 \times e^{-kt} \]

\[ \frac{C}{C_0} = e^{-kt} = 0.05 \]

\[ t = \frac{\ln(0.05)}{-k} \, (h) \]

where \( k \) is \( \frac{ECR}{50 \, m^3 \, (h^{-1})} \)

6.3.7 Calculation of ozone production

The calculation is carried out by means of the equation shown below and must only be regarded as a guide-line calculation:

\[ C = \frac{q}{n \cdot V} (1 - e^{nt}) + (C_0 - C_i) e^{-nt} + C_i \]

where

\[ C = \text{ozone concentration in the chamber} \, (m^3/m^3) = (ppm); \]
\[ V = \text{volume of the chamber} \, (m^3); \]
\[ q = \text{quantity of pollution added} \, (m^3/h); \]
\[ \tau = \text{time} \, (h); \]
\[ n = \text{air exchange rate} \, (h^{-1}); \]
\[ C_i = \text{pollution concentration in the injection air} \, (m^3/m^3); \]
\[ C_0 = \text{pollution concentration in the chamber} \, \tau = 0 \, (m^3/m^3); \]

As \( C_i \) and \( C_0 \) are set equal to zero, the following expression is obtained:

\[ C = \frac{q}{n \cdot V} (1 - e^{nt}) \]

The value of \( n \) is chosen on the basis of measurements of the natural air exchange rate (6.3.3a) and \( q \) can thus be calculated by using the following equation:

\[ q = \frac{C \cdot n \cdot V}{1 - e^{-nt}} \, (m^3/h) \]

\[ C(mg/m^3) = \frac{M}{24.45} \cdot C \, (ppm) \]

where:

\[ M \] is the molecular weight of the substance (\( M \) (ozone) = 48)

Before beginning the test, the room must be completely free of ozone. Close the door and start the air cleaner. A sample is taken eg. after 8 hours and again after eg. 16 hours via a measuring tube. The door is not to be opened before the test is finished.

As an alternative the ozone production from the air cleaner can be measured directly with an UV-spectrophotometer eg. Dasibi 1003 AH and Dasibi 1008 RS in surroundings free of tobacco smoke. The measuring apparatus must be calibrated before measuring.

The ozone concentration in the air leaving the air cleaner is measured by traversing over the outlet of the air cleaner and at the lowest stream of air through the air cleaner.

Ozone production from air cleaners without a fan can be determined by placing the air cleaner in a small wind tunnel. The ozone concentration is measured in the outlet of the wind tunnel.

The ozone production is calculated as:

\[ q \, (m^3/h) = C \, (ppm) \times q_{air} \, (m^3/h) \]

The threshold value for ozone (July 1994, DK) is 0.1 ppm or 0.2 mg/m³.
6.4 Expression of results

Portable air cleaner descriptions and results.

<table>
<thead>
<tr>
<th>Device number</th>
<th>Device description</th>
<th>Retail costs (DKK)</th>
<th>Speed</th>
<th>Power (Watts)</th>
<th>Flow rate (m³/h)</th>
<th>ECR (m³/h/Watt)</th>
<th>Efficiency (%)</th>
<th>ECRR (mg O₃/h/Watt)</th>
<th>Ozone (mg O₃/h)</th>
<th>CCT5% (h)</th>
<th>Ozone:</th>
</tr>
</thead>
<tbody>
<tr>
<td>EX1</td>
<td>Electric filter and negative ion-generator</td>
<td>600</td>
<td>high</td>
<td>50</td>
<td>32</td>
<td>112</td>
<td>97</td>
<td>86</td>
<td>3.0</td>
<td>&lt;1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

1) Retail costs obtained from manufacturers or local distributors
2) Efficiency calculated as the observed effective cleaning rate (ECR) divided by the measured air flow rate (±95 % confidence limits)
3) Effective cleaning rate (ECR) calculated as the flow rate of particle free air required to produce the observed decay rate in cigarette smoke (±95 % confidence limits)
4) ECR divided by the power consumption
5) Calculated cleaning time to reduce the initial concentration of particles from 100 % down to 5 % with reference to 50 m³ test chamber

6.5 Accuracy

- Power consumption: 0-100 Watt ±1 Watt
- 0-200 Watt ±2 Watt
- Flow rate: Measured flow rate ±5 %
- ECR: 10-500 m³/h ±95 % confidence limits
- SE: ±95 % confidence limits
- ECRR: Not calculated
- CCT5%: Not calculated
- Ozone: Not calculated

6.6 Test report

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organisation or the person who ordered the test
d) Purpose of the test
e) Method of sampling and other circumstances (date and person responsible for sampling)
f) Name and address of manufacturer or supplier of the tested object
g) Name and other identification marks of the tested object
h) Description of the tested object
i) Date of supply of the tested object
j) Date of the test
k) Test method
l) Conditioning of the test specimens, environmental data during the test (temperature, pressure, RH, etc.)
m) Identification of the test equipment and instruments used
n) Any deviation from the test method
o) Test results (use SI units)
p) Inaccuracy or uncertainty of the test result
q) Date and signature
CALCULATING THE DECAY

The decay constant, \( k \), for particulate matter is based on the formula:

\[
C_t = C_0 e^{-kt}
\]

where

\( C_t \) = concentration at time \( t \) (particles/cm\(^3\))
\( C_0 \) = initial concentration at \( t = 0 \) (particles/cm\(^3\))
\( k \) = decay constant (hours\(^{-1}\))
\( t \) = time hours

The decay constant, \( k \), is obtained by linear regression on \( \ln C_t \) and \( t \) using the following formula:

\[
k = \frac{\frac{1}{n} \sum_{i=1}^{n} t_i \ln C_t_i - \left( \frac{1}{n} \sum_{i=1}^{n} t_i \right) \left( \frac{1}{n} \sum_{i=1}^{n} \ln C_t_i \right)}{\frac{1}{n} \sum_{i=1}^{n} t_i^2 - \left( \frac{1}{n} \sum_{i=1}^{n} t_i \right)^2}
\]

where

\( t_i \) = time at time \( i \)
\( \ln C_t_i \) = natural logarithm of the concentration at time \( t_i \) in particles/cm\(^3\)
\( n \) = number of acceptable data points (\( n \geq 10 \))

When the above calculations are used for natural decay measurements, the results represent the natural particulate matter reduction in the room air.

When the above calculations are used for particulate matter removal measurements, the results represent the natural particulate matter reduction plus the air cleaner performance in room air.
DETERMINING THE COEFFICIENT OF DETERMINATION

The coefficient of determination expresses the fraction of the variation between the dependent and independent variables which is accounted for by the relationship determined by linear regression.

It can be calculated by using the following equations:

\[ r^2 = \frac{S_{xy}^2}{S_{xx}S_{yy}} \]

where \[ S_{xy} = \sum_{i=1}^{n} \ln C_i \cdot \left( \frac{1}{n} \left( \sum_{i=1}^{n} \ln C_i \right) \right) \]
\[ S_{xx} = \sum_{i=1}^{n} t_i^2 - \frac{1}{n} \left( \sum_{i=1}^{n} t_i \right)^2 \]
\[ S_{yy} = \sum_{i=1}^{n} \left( \ln C_i \right)^2 - \frac{1}{n} \left( \sum_{i=1}^{n} \ln C_i \right)^2 \]

where \[ r^2 = \text{coefficient of determination} \]
\[ t_i = \text{time at the } i\text{th data point in hours} \]
\[ \ln C_i = \text{natural logarithm of the concentration at time } t_i \text{ } \text{particles/cm}^3 \]

Step 1: Calculation of Standard Deviation of a Regression Line

An estimate of the standard deviation of the regression line is calculated as follows:

\[ S_{\text{reg}} = \sqrt{\frac{1}{n-2} \sum_{i=1}^{n} \left( \ln C_i - b - mt_i \right)^2} \]

where \[ S_{\text{reg}} = \text{estimated value of the overall standard deviation} \]
\[ n = \text{the number of pairs of data points used in the regression} \]
\[ b = \text{the intercept of the regression line (equivalent to an estimated initial concentration) in particles/cm}^3 \]
\[ m = \text{the slope of the regression line, equivalent to the calculated value } k \text{ (l/hours)} \]
\[ t_i = \text{time at the } i\text{th data point in hours} \]
\[ \ln C_i = \text{natural logarithm of the concentration at time } t_i \text{ in particles/cm}^3 \].

Step 2: Calculation of Standard Deviation Estimate of the Regression Line Slope

The Standard Deviation Estimate of the slope of the regression line is calculated as follows:

\[ S_{\text{slope}} = \sqrt{\frac{S_{\text{reg}}^2}{S_{xx}^2}} \]

where \[ S_{\text{reg}} \text{ and } S_{xx} \text{ are already calculated.} \]
PERFORMANCE CALCULATIONS

The performance of a portable room air cleaner is represented by a clean air delivery rate (ECR). A method for calculating the clean air delivery rate is:

\[
\text{Clean air delivery rate} = V (k_e - k_n) \text{ (m}^3\text{/h)}
\]

where

- \(V\) = volume of test chamber, m\(^3\)
- \(k_e\) = measured decay rate in hours\(^{-1}\), 1 \(t/\text{h}\)
- \(k_n\) = natural decay rate in hours\(^{-1}\), 1 \(t/\text{h}\)

This method of determining the performance of portable room air cleaners is applicable to any cleaning technology known at present.

6.7 Calculation of the Standard Deviation

Estimate of the ECR for a single test

The standard deviation estimate as described above for each of the natural and total decay lines can be combined using error propagation analysis on the equation used to compute the ECR.

The test chamber volume is taken as a constant for the purposes of this analysis and the following equation is used to estimate the standard deviation for the ECR computed for the pair of regression lines.

\[
S(\text{ECR}) = 50.6 \sqrt{S(\text{slope, } k_e)^2 + S(\text{slope, } k_n)^2}
\]

where

- \(S(\text{ECR})\) = the estimated standard deviation for ECR
- \(S(\text{slope, } k_e)\) = the estimated standard deviation of the total decay rate
- \(S(\text{slope, } k_n)\) = the estimated standard deviation of the natural decay rate
- 50.6 = the volume of the test chamber, treated as a constant, which is used to put the estimated standard deviation value on an ECR basis.
The test chamber is an empty room with for example the following inside dimensions:

\[ W \times L \times H : 4.5 \times 4.5 \times 2.5 = 50.6 \text{ (m}^3\text{)} \]

Other reasonable dimensions will be acceptable, but the volume of the room shall be \( 50 + 10 \text{ m}^3 \).

The building envelope is for example constructed from IWO Terming pre-fabricated elements for refrigerating/freezing rooms (phosphated and fire-coated 0.8 mm steel plates) which have a very smooth surface.

(1) Circulating fan (25 Watt), see Photograph No. 1.
(2) Ashtray for smoke produced by Danish Red Prince cigarette (as default) burning naturally, see Photograph No. 2.
(3) Portable room air cleaner placed \( = H/2 \text{m} \) above floor level, see Photograph No. 3.
(4) Optical particle counter, see Photograph No. 4.
(5) Instrument to measure and control the test chamber temperature and humidity, see Photograph No. 5.
Photograph No. 3. Portable room air cleaner placed = H/2m above floor level.

Photograph No. 4. Optical particle counter for example LAS-X.

Photograph No. 5. Instrument to measure test chamber temperature and humidity, for example Briel & Kjær Type 1213.

Photograph No. 6. Instrument to measure ozone, for example Dräger Tube Ozone and Dräger Multi Gas Detector Model 31.
REFERENCES


2) "Luftrenares effekt på tobaksrök" (The effect of air cleaners on tobacco smoke), Lars Olander, Johan Johansson & Rolf Johansson, 1987 (in Swedish).

3) "Luftrenares effekt på tobaksrök, Del II, Långtidsprov och kompletterande måttningar" (The effect of air cleaners on tobacco smoke, Part II, Long term tests and additional measurements), Lars Olander, Johan Johansson, Rolf Johansson, 1989 (in Swedish).


6) "What is Ventilation Efficiency?", M. Sandberg, 1981.


NT CONS 009 is more comprehensive (complex and expensive) than this method and therefore more useful in research- and development work.