Standard ECMA-328
August 2001

ECMA

Standardizing Information and Communication Systems

Detection and measurement of chemical emissions from electronic equipment

Phone: +41 22 849.60.00 - **Fax:** +41 22 849.60.01 - **URL:** http://www.ecma.ch - **Internet:** helpdesk@ecma.ch

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Brief History

Indoor environments represent a unique environmental niche. In addition to the incursion of pollutants from outdoor air, most indoors built environments have air pollutant sources that release fibres, particles, organic vapours and inorganic gases. Thus, it should not be surprising to find that some indoor environments are more polluted than their corresponding outdoor environments. The occurrence of indoor air pollution is dependent upon many factors, which in and of them, vary temporally and spatially. Factors such as the design, building materials/furnishings, ventilation, operation and maintenance of the building, occupant work activities and associated equipment/appliances all contribute to exposure of occupants to indoor air pollutants. While scientific studies and public health surveys attempt to address the potential risks to public health related to indoor air pollutants, it is prudent to implement effective risk management to reduce levels of indoor air pollutants. One approach to improve indoor air quality is to assure that the chemical emissions from products used within the indoor built environment are known, and steps taken to minimize their contribution to indoor air pollution concentrations within the indoor built environment.

This ECMA Standard seeks to address the issue of chemical emissions from electronic equipment through the development of scientifically-sound, flexible, and cost-effective methods that can be used to determine volatile organic compounds (VOC), ozone and particulate matters emitted from electronic products. The methods are designed for the evaluation of emissions that may need control to ensure minimum impact on indoor air quality, and for the characterisation of electronic equipment as supplied to the marketplace.

Using these methods, it is anticipated that high emitting materials can be identified and eliminated from use, while low-emitting materials can be identified and introduced into production where feasible.

This ECMA Standard has been developed by ECMA TC38.

This ECMA Standard has been adopted by the ECMA General Assembly in August 2001.

Table of contents

1 Scope

This Standard ECMA-238 addresses methods for determining chemical emissions from electronic equipment with a rated voltage not exceeding 1000 V rms, intended for domestic or professional indoor use.

The chemical emissions specifically addressed by this standard are volatile organic compounds (VOC), ozone and particulate matter. Testing is to be done within a carefully controlled test chamber environment.

The results obtained with this measurement method are not suitable for extrapolation to real indoor situations, but can be used to estimate the potential chemical emission of electronic equipment and to compare equipment of the same class.

The requirements of this ECMA Standard are intended to complement, but not supersede, applicable standards, laws, or regulations.

2 Conformance

Apparatus intended for emission testing conforms to this standard only when the apparatus is built and operated according to clauses 6 and 7, subjected to a quality control plan as defined in clause 9 and if the results are reported according to clause 8.

3 References

ISO 554:1976	Standard atmospheres for conditioning and/or testing - Specifications
ISO 16017-1:2000	Indoor ambient and workplace air - Sampling and analysis of volatile organic compounds by sorbent tube / thermal desorption / capillary gas chromatography - Part 1: Pumped sampling
EN 1232:1997	Workplace atmospheres - Pumps for personal sampling of chemical agents - Requirements and methods

4 Definitions

For the purpose of this Standard the following definitions apply.

4.1 Air changes per hour (ACH)

A way of expressing an air exchange rate. The volume of air is commonly expressed in terms of the volume of a structure (e.g. a test chamber or room) and one hour is typically used as the time unit. Hence, for a 20 m^3 chamber, one ACH would be equal to 20 m^3/hour.

4.2 Air exchange rate

The rate at which interior air (e.g. air within a chamber) is exchanged with exterior air (e.g. supply air exterior to a chamber). The rate is expressed as the volume of air exchanged per unit of time.

4.3 Air flow rate

The volume or mass of air entering into the environmental chamber per unit of time.

4.4 Air velocity

The air speed over the surface of the EUT, measured at a distance of 10 cm to 20 cm from the surface.

4.5 Ambient concentration

The background concentration of a compound found in a specified environment.

4.6 Environmental chamber

An enclosed chamber of appropriate size, construction and materials to allow detection and quantification of volatile organic compounds, ozone and particulate matter under tightly controlled environmental conditions.

NOTE

Depending on the EUT, parameters such as the size of the chamber typically vary from 100 litres to several *cubic meters. It is obvious that in small chambers parameters as operator position will be impossible to ascertain.*

4.7 Equipment loading factor

Ratio of the exposed volume or area of an EUT to the free volume of the environmental chamber.

4.8 Equipment under test (EUT)

Complete electronic device including accessories.

4.9 Ozone

CAS No. 10028-15-6, triatomic oxygen.

4.10 Particulate matter

Organic or inorganic matter containing no asbestos and < 1 % crystalline silica.

- **Inhalable particulate matter** refers to all particles that may enter the mouth or nose by breathing particulate matter, generally with aerodynamic diameter < 1 mm.
- **Respirable particulate matter** is the part of inhalable particulate matter that may reach the gas-exchange parts of the lungs, with aerodynamic diameter < 10 µm.

4.11 Relative humidity (rH)

The concentration of water vapour in air compared to the maximum concentration of water vapour that air, at that specific temperature, could contain. Because of its comparative nature, relative humidity is expressed as a percentage.

4.12 Specific emission rate

The rate of emission of a mass of analyte (e.g. VOC, ozone or particulate matter) from an EUT per unit of time at a given time from the start of the test (e.g. µg/EUT/hour), per mass of product (e.g. µg/mg of toner) or per unit of area of product (e.g. µg/m^2 of polymer).

4.13 Total Volatile Organic Compounds (TVOC)

The sum of the concentrations of identified and unidentified volatile organic compounds between and including n-hexane and n-hexadecane; the areas of unidentified peaks are converted to concentrations using the toluene response factor.

4.14 Very Volatile Organic Compounds (VVOC)

Carbon containing compounds having a boiling point below 70 °C.

4.15 Volatile Organic Compounds (VOC)

Carbon containing compounds having boiling points between 70 °C and 240 °C.

5 Acronyms and abbreviations

ACH	Air Changes per Hour	**PTFE**	Polytetrafluoroethene
EUT	Equipment Under Test	**QA**	Quality Assurance
FID	Flame Ionisation Detector	**QAPP**	Quality Assurance Project Plan
HEPA	High Efficiency Particulate Arrestance	**QC**	Quality Control
GC/MS	Gas chromatography/Mass spectrometry	**TVOC**	Total Volatile Organic Compounds
rH	Relative humidity	**VOC**	Volatile Organic Compounds
SERu	Unit Specific Emission Rate	**VVOC**	Very volatile Organic Compounds

6 Environmental chamber definition

Testing of equipment for fugitive chemical emissions shall occur under carefully controlled conditions, in environmental chambers with both environmental control and monitoring capabilities, specifically constructed for EUT emissions testing.

6.1 Materials and construction

The preferred materials for chamber constructions are polished stainless steel or stainless steel. Glass and aluminium are also accepted.

6.2 Chamber dimensions and volume

Chamber dimensions shall be defined according to the size and functional attributes of the EUT. To determine the applicability of equipment loading factors, the EUT-to-chamber volume ratio shall be in the range of 1:2,5 to 1:20.

6.3 Operational capabilities

Required environmental and operational set points are defined below.

- **Operating temperature**
  Operating temperature shall be 23 °C ± 2 °C, according to ISO 554.

- **Operating relative humidity**
  Operating relative humidity shall be 50 % ± 5 %, according to ISO 554.

- **Chamber background requirements**
  The following background levels shall be maintained within a chamber and controlled regularly by applying the methods described in 7.3 to 7.5:
  - VOC: < 2,0 µg/m³ for any single species;
  - TVOC: < 50 µg/m³;
  - Ozone: < 4 µg/m³;
  - Particulate matter: < 10 µg/m³.

- **Chamber supply air requirements**
  Supply air, required in the case of chambers operated under the equilibrium approach, shall be filtered and/or treated to such an extent that it contains levels of VOC, particulate matter and ozone lower than the background contamination of the chamber.

  Air supply rates shall be in the range of 0,5 ACH to 2,0 ACH.

- **Positive chamber pressurisation requirement**
  A slight positive pressure (2 Pa – 10 Pa) shall be maintained throughout the test to avoid possible contamination of the chamber atmosphere.

- **Chamber air mixing requirements**
  Variations in concentrations within a chamber, at any point in time, shall be no more than 10 %.

  NOTE
  It is recommended that mixing within a chamber be tested while the EUT is within the chamber to assure that adequate mixing is achieved with the typical EUT volume in place.

6.4 Testing approaches

Two approaches can be used in testing, equilibrium testing and non-equilibrium testing. The equilibrium approach can be used for both constant emitting sources and non-constant emitting sources. The non-equilibrium approach can be used only for constant emitting sources.

NOTE
When an EUT is placed in a clean measurement chamber, the concentration of VOC will build up. In annex A, a mathematical derivation is given for the simple case of 1 VOC emitted from one EUT in the chamber with a known, constant air exchange rate after the EUT has been switched on. During the build-up period, the concentration of a VOC is not constant i.e. there is no equilibrium. The concentration of a VOC will reach (quasi)-equilibrium in approximately four chamber air changes.

- **Equilibrium approach**
  In the equilibrium approach, the chamber operation is aimed at determining both build-up and equilibrium concentrations for VOC and particulate matter. When testing equipment within a chamber that is provided with a constant supply of air and a constant level of exhaust, it is required that the supply air and exhaust be co-ordinated such that under-pressurisation or over-pressurisation of the chamber is precluded. It is also required that supply air be provided at a constant rate that does not

vary more than 10% (e.g. 4 ACH ± 0,40 ACH). It is recommended that the chamber be sufficiently airtight to avoid uncontrolled air exchange with external air. Air leakage shall be either less than 0,1 % of the chamber volume per minute at an overpressure of 1 kPa or less than 1 % of the supply airflow rate.

- **Non-equilibrium approach**
  In the non-equilibrium approach, the chamber is operated in such a manner that VOC and particulate matter concentrations are building up and will not attain equilibrium values. It is required that the chamber be operated in such a manner that airborne contaminants from the ambient environment outside the chamber do not enter the chamber during testing. Concentrations of the blank measurements (particulate matter, VOC) must be below chamber background levels.

7 Test method

7.1 Handling of equipment under test

7.1.1 Selection

The equipment to be tested shall have been manufactured, packaged and handled in the normal manner. Newly manufactured equipment with minimum operating time shall be used for emissions testing. Active conditioning of the EUT, unless part of the normal manufacturing process, shall not be performed on products prior to chemical emissions testing.

For equipment coming back from the field, protection procedures shall start at the moment of reception of the equipment.

Equipment shall be shipped to the test laboratory as soon as possible. During shipment, the equipment shall be thoroughly protected from chemical contamination or any physical exposure (e.g. heat and humidity). This can usually be achieved by wrapping each part separately in aluminium foil and in a polyethylene bag or alternatively, in aluminised packaging (shiny side out) lined with polyethylene or clear polyvinyl fluoride film.

On arrival, equipment shall be stored in the original shipping containers at ambient indoor conditions (23 °C ± 2 °C). It is recommended to start emission testing immediately after the sample has been taken from the manufacturer and transported to the testing laboratory. In order to avoid stronger effects of ageing of the equipment, it shall be wrapped in an airtight, inert package during any period of storage.

The following information should be recorded and kept with the equipment documentation:

- date of manufacture, if known,
- number of hours the equipment has been used while energised during manufacture and testing, if available;
- serial number;
- model number;
- external dimensions.

NOTE
Due to possible variation between similar equipment, it may be necessary to test more than one equipment of the same type or configuration to determine an emission rate.

7.1.2 Preparation of the equipment for testing

The equipment to be tested shall be removed from the shipping containers and all protective shipping packaging such as spacers, film wrapping and any other shipping/packaging elements shall be removed prior to placement in the chamber. Each equipment should be examined and a determination made if the operating limitations of the equipment will allow for a full test period. For example the equipment, operating a full duty cycle, may consume supplies such as inks, toner, ribbons and paper. Prior to test, the length of time the equipment can operate without replenishment of supplies shall be determined and compared to the planned test time.

Following the removal of all packaging/shipping elements, the EUT shall be placed in the chamber in a power-off mode for a minimum of 4 hours prior to initiation of testing. This period can be combined with the chamber purging cycle.

7.1.3 Equipment operation during testing

This standard is intended to cover a wide range of consumer and commercial electronic equipments. Guidelines on how specific equipment is to be operated during testing must be flexible enough to allow testing of this broad range of equipment. For the purposes of this standard, equipment for which operational factors during testing are discussed, will be divided into two categories:

- Equipment that does consume supplies during operation (see 7.1.3.1).
- Equipment that does not consume supplies during normal operation; (see 7.1.3.2).

7.1.3.1 Equipment consuming supplies

Examples of equipment that consume one or more types of supplies in their normal operation are printers, copiers, and fax machines. Given the broad range of equipment covered under this category, it is imperative that the duty cycle of the equipment be taken into consideration prior to setting the operational factors to be used during the test. It is useful to test this type of equipment while operated at its maximum duty cycle.

For this category of equipment, VOC, ozone and particulate matter emissions should be determined.

7.1.3.2 Equipment not consuming supplies

Examples of equipment that does not consume supplies are: monitors, TV sets, servers, desktop computers, portable computers, tape backup units, stereo music systems. Equipment shall be tested under typical operational conditions and modes. After setting operational modes and controls to normal use ranges the equipment should be "exercised" continuously throughout the test.

For this category of equipment, the main focus should be toward determination of VOC emission.

7.2 Environmental chamber operation

Using a chamber of appropriate size and material construction as outlined in 6.1 and 6.2, the EUT shall be placed centrally in the chamber. Regardless of whether the chamber is operated under equilibrium or non-equilibrium approaches, any air supplied to the chamber shall be filtered. Incoming air shall be filtered first for coarse impurities such as dust, by a pre-filter, then for organic oil vapours by activated charcoal, then by an after filter, and finally through a HEPA filter. Dehumidification systems shall be located upstream of the supply air filter system, pre-cleaned pressurised, dried and filtered air is thus delivered to the chamber.

Mixing shall be achieved by a duct-installed centrifugal flow fan or by a variable speed fan internal to the chamber. Depending upon prevailing atmospheric conditions, the chamber may also need to be fitted with means for further controlling temperature and humidity. While many approaches may be used, the chamber environmental performance defined in 6.3 shall be achieved.

Supply air rate, relative humidity and temperature shall be controlled by appropriate mechanisms. Periodic measurements of these three parameters shall be automatically recorded and the measurements shall be retained by the recording system. Hard copy records shall be produced and retained with the emissions test data. In this manner, all environmental chamber parameters (temperature, relative humidity - incoming supply air and chamber interior -, supply air flow, fan speed etc.) shall be controlled and recorded.

Chamber penetrations shall be sealed using a low-volatile caulk to eliminate sources of air leakage and prevent background VOC contamination.

7.2.1 Environmental chamber pre-conditioning

The interior walls of the chamber shall be cleaned using a vacuum cleaner for the floor and a cloth dampened with distilled or deionized water for the walls and ceiling.

If suspected chamber interior contamination exists, such as may occur when documented by a previously high value for a chamber blank measurement, the walls can be rinsed repeatedly with distilled or deionized water. Dry the interior surfaces with a polyester cloth or similar material.

In cases of known carry-over VOC contamination, additional overnight thermal desorption (for example 240 °C for 6 h under maximum ventilation conditions of supply air) can be performed if permitted by the chamber construction.

After chamber cleaning procedures, the chamber shall be purged with filtered air for four chamber air volumes.

Specific chamber preconditioning is defined for each of the testing methods described in 7.3, 7.4 and 7.5.

Prior to introducing the EUT into the chamber, background VOC, ozone and particulate matter sampling shall be conducted to determine if background levels exceed the values defined in 6.3.

After purging, chamber background samples for VOC, ozone and particulate matter shall be collected in duplicate.

7.2.2 Chamber operating parameters

- **Temperature**
  Chamber temperature controls shall be adjusted to maintain the temperature defined in 6.3. The internal chamber temperature shall be measured during testing using a traceable calibrated thermometer or thermocouple and recorded.

- **Humidity**
  The relative humidity controls shall be adjusted to maintain the humidity defined in 6.3 by means of a traceable calibrated measuring device.

- **Chamber Integrity**
  Leakage rate shall be integrated into the ventilation measurements obtained. The chamber should be operated at an overpressure of 2 Pa to 10 Pa. The chamber static pressure shall be measured using an appropriate instrument or other controller and recording systems. At a maximum, the leakage rate shall be < 200 Pa/chamber volume/hour.

  NOTE
  The tracer gas decay method uses inert gases measured directly by a dedicated GC for that purpose. For maximum accuracy and precision, the decay curve is obtained simultaneous to the product emissions test. Tests performed demonstrate that there is no interference or interaction between the inert gases used (CO2) and the VOC emitted by the product.

- **Mixing**
  Mixing shall be achieved using either a duct-installed centrifugal flow air recirculation fan or internal chamber fan during the emissions test. Interior chamber fans should be mounted appropriately to allow for thorough mixing. Using a speed controlled fan with magneto coupled transmissions avoids contamination of the internal chamber environment and allows air speed control.

  NOTE
  Mixing requirements depend strongly on chamber size.

- **Supply air system**
  All filters on the air supply system shall be replaced or cleaned at regular maintenance intervals, depending on chamber size and air ambient characteristics.

- **Chamber ventilation rate**
  Air change rates shall be monitored using appropriate instrumentation. Calibrated mass flow controls or other instrumentation such as a pitot tube can be used depending on the chamber size.

7.3 Volatile organic compounds (VOC) detection and analysis

7.3.1 Background

VOC emissions shall be determined during continuous operation of the EUT for a specified period (e.g. minimum 4 h) in the chamber (conditioning time prior to sampling is dependent on ACH rate). The airborne samples shall be collected on adsorbent tubes using calibrated low volume sampling pumps. The pumps shall fulfil the requirements of EN 1232 or equivalent.

Two types of sorbent tubes can be used.

- Tenax TA (60-80 mesh), at least 200 mg per tube, shall be used for VOC (mandatory);
- Equivalent volumes of NIOSH 2549 type, active carbon and molsieve, shall be used for VVOC.

Due to sensitivity of active carbon towards humidity, the use of Tenax TA is mandatory in all cases, see ISO 16017 for details.

NOTE
Sampling of VOC and VVOC can be carried out at the same time, using Tenax as the front tube and Chromosorb 106 as a back-up tube.

7.3.2 Procedure

Sample collection shall be conducted under the following guidelines:

Preparation

- Sorbent tubes shall be prepared prior to each sampling by heating at 280 °C to 320 °C and purging with an inert gas (e.g. helium) at a rate of 100 ml/min for 10 min.
- Tenax tubes shall be spiked with an internal standard (for example deuterated toluene dissolved in methanol) in the expected concentration range for quantification.
- A field blank shall be collected before each test to determine any background contribution to VOC from the empty chamber.
- One Tenax tube shall be spiked with n-hexane and n-hexadecane. This sorbent tube shall be analysed under the same chromatographic conditions of all the other samples. The time region between these two substances shall be used for the estimation of the TVOC values.

Operation

- Install the EUT in the chamber. Insertion into the chamber has to be carried out as fast as possible to avoid contamination of the test atmosphere with ambient air.
- Begin operating the EUT. Record this time as $t = 0$.
- Sample collection:
  - EUT consuming supplies (see 7.1.3.1):
    Collect samples at regular intervals (e.g. 15 min to 60 min) from t_0 until the end of the sampling period (e.g. 2 h to 4 h).

    NOTE
    In case of the equilibrium approach, two samples are to be collected either closely before or after the chamber concentration reaches equilibrium.
  - EUT not consuming supplies (see 7.1.3.2):
    Collect samples at intervals (from $t = 0$) of 1 hour, 2 hours, 4 hours, 6 hours, and 8 hours.
- Sample storage:
  After sampling, sorbent tubes shall be capped with PTFE or metal caps on both ends of the tubes, and secured in a stainless steel or Teflon cylinder as soon as the sample tube is removed from the sampling tube holder.

  Store the cylinder at a temperature of approximately 4 °C until analysis. Sorbent tubes shall be analysed as soon as possible but within 1 week.
- Sample Analysis:
  Sampled tubes shall be thermally desorbed (10 min at 300 °C) to a cold trap down to –150 °C which, when heated quickly, transfers the trapped compounds to a Gas Chromatography (GC) column.

  NOTE
  Bonded 100 % dimethylpolysiloxane columns of 30 m to 50 m, internal diameter of 0,25 mm to 0,35 mm and phase thickness 0,25 µm to 0,33 µm are examples of columns suitable for VOC analysis.

  This separates the adsorbed compounds which upon leaving, are analysed with a Mass Spectrometer (MS), for identification and quantification, or a Flame Ionisation Detector (FID), for quantification. The analytical instrumentation shall be calibrated with either gaseous or liquid external standards.

  Formaldehyde and other aldehydes and ketones emissions sampling shall be conducted using a traceable method.

7.3.3 Interpretation

In all cases, the MS trace shall be used to identify all airborne substances (with retention times comprised between n-hexane and n-hexadecane), in terms of chemical identity and quantity sampled. The individual airborne concentration of these compounds shall be calculated by using the response factor of deuterated toluene. All quantitative measurements shall be corrected by means of the background measurements made before the emission measurement.

7.4 Ozone detection and analysis

7.4.1 Background

The ozone emission rate (E, µg/min) shall be determined during continuous operation of the EUT. Conditions shall be maintained within the limits defined in 6.3.

During continuous operation, the ozone concentration at the operator position in the chamber reaches a maximum equilibrium value ($c_{\max}$). The ozone decay constant, k, shall be determined from the ozone decay curve after powering off the product. The ozone emission rate, E, is calculated from $c_{\max}$, k, and V using the following formula:

$$E = \frac{c_{\max} k' VP}{TR} \qquad \textbf{(1)}$$

where:

- E Emission rate [µg/min];
- c_{max} Maximum equilibrium ozone concentration value [µg/m^3];
- V Chamber air volume [m^3];
- P Atmospheric pressure [Pa];
- T Ambient temperature [K];
- R Gas conversion constant [Pa/K].

For Ozone, the value of the gas conversion factor is: 339,8 [Pa/K]

NOTE
The volume of the chamber (V) is converted from pressure and temperature when measuring ozone, to SATP: Standard Ambient Temperature and Pressure (1 atm = 101 325 Pa) and temperature (25 °C). This correction is performed because most ozone analysers display ozone concentration at SATP.

$$k' = k + A$$

where:

- k Ozone decay constant [min^{-1}];
- A Room ventilation rate [min^{-1}].

Furthermore:

$$k' = \frac{\ln 2}{H'}$$

where:

- H' Ozone half-life (min), time for the ozone concentration to fall to $c_{max}/2$.

Alternatively, once the chamber ozone level reaches c_{max}, the chamber ozone concentration is boosted to approximately 0,1 ppm above c_{max}. With the EUT still running, the ozone concentration is recorded until the chamber level returns to c_{max}. Then, the ozone emission rate, E, is calculated with equation 2 below:

$$E = \frac{c_{\max} k'' VP}{TR} \qquad \textbf{(2)}$$

where:

$$k'' = k + A + B$$

$$B = F\frac{Q}{V}$$

where:

- B Ozone filtering capacity of the EUT;
- F Ozone filtering factor of the EUT
  (no filtration: $F = 0$; complete filtration: $F = 1$);
- Q Volumetric flow of air, expelled from the EUT [m^3/min].

If an ozone filter is present in the EUT, then the ozone filtering factor shall be determined by measuring ozone concentrations and volumetric flows at the exhaust with and without ozone filter.

The following formula can be used for one exhaust port:

$$F = \frac{\left(Q_a c_a - Q_p c_p\right)}{Q_a c_a}$$

where:

- Q_a Flow without ozone filter (m^3/min)
- c_a Ozone concentration without ozone filter (µg / m^3)
- Q_p Flow with ozone filter (m^3/min)
- c_p Ozone concentration with ozone filter (µg / m^3)

Note
The ozone filtering factor thus denotes how much ozone is removed from the filtered ozone flow in comparison to the total amount of ozone present in the flow before entering the filter. No filtration: $F = 0$; complete filtration = 1.

If more exhaust ports are present, where ozone filtered air exits the EUT, then ozone filtering capacities (Bi) should be summed, before substituting these in formula (2).

Furthermore:

$$k'' = \frac{\ln 2}{H''}$$

where

- H'' Ozone half life [min], time for the ozone concentration to fall to $(c_{max} + c_0)/2$;
- c_0 Highest ozone concentration value, reached at the end of the time when extra ozone is injected.

For practical purposes, the ozone emission / generation rate can be calculated from either equation 1 or equation 2 by using either k' or k'' respectively, together with c_{max}, V, p and T.

The use of equation 1 and 2 is demonstrated in figure 1.

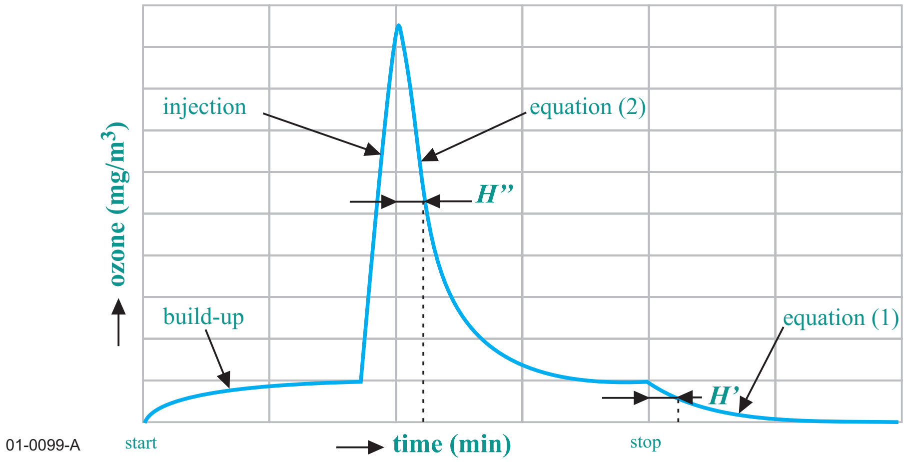

Figure 1 – Example of application of equations 1 and 2

“Start” and “stop” refer to the beginning, respectively the termination of the continuous EUT operation.

The chamber decay half-life (H =(ln2)/k) which is the half-life for a chamber ventilation rate of zero air changes, can be determined from equation 1 or 2, when variables in the equations, including the chamber ventilation rate, are known. However, the method can still be used for chambers with unknown, low ventilation rate and EUT ozone filtering factor: since it is possible to record an apparent half-life, *H’* or *H”*, including the chamber ventilation rate and ozone filtering factor. By substituting the calculated *k’* or *k”* in equation 1 or equation 2, it is possible to determine the ozone generation rate.

NOTE
When using the alternative boosted ozone method, chamber ozone concentrations can be increased by using any of several commercial ozone generating devices. Most of these devices consist of a fan blowing air through a tube in which are contained energised high voltage wires.

As is apparent from the preceding clause, the ozone filtering capacity of the EUT shall be taken into account. It is deduced either from differences in the decay curves with the product running in continuous operation mode and with the EUT turned off, or from ozone production measurement at outlets (sum of products of ozone concentrations at outlets and volumetric flow), or both.

7.4.2 Procedure

Since ozone is a transient species, it must be sampled and analysed instantaneously. Continuous recording monitors are available and operate on UV-absorbance or chemiluminescent principles.

The response must be calibrated in accordance with the manufacturer's instructions. The minimum performance parameters for ozone analysers shall be:

- Range (ppm full scale): 0,01, 0,02, 0,05, 0,1, 0,2, 0,5 and 1 (or autoranging);
- Minimum detectable sensitivity (lower detection limit): ≤ 2 ppb;
- Precision: ± 2% from mean value on the 0 ppm to 0,1 ppm range (1 ppb or 1% full scale);
- Sampling rate (may be important for small chambers): ≤ 5 l/min.

The ozone analyser shall be placed in a control room outside the main chamber. The sampling line shall be of minimum length, not exceeding 4 m, and made of a flexible inert material such as PTFE; the preferred dimensions are outer diameter 6 mm, and inner diameter 4,5 mm.

Before testing starts, surfaces of the chamber and EUT shall be deactivated by exposure to an ozone concentration of 0,1 ppm to 0,2 ppm for sufficient time to ensure that ozone decay rate represents the normal value for the chamber. The normal decay rate shall be < 0,0693 min^{-1} which corresponds to an ozone half-life of > 10 min.

Prior to operation of the EUT, the chamber ozone concentration shall be monitored for a minimum of 10 min. At the end of this period, the ozone chamber "blank" should be < 2 ppb, and the ozone concentration at the ventilation inlet should be < 2 ppb.

Ozone shall be monitored at the operator position, located at height 1,2 m above the floor and 0,3 m from the equipment, during continuous operation either for at least one hour, or for as long as it takes to determine the build-up and stabilisation of ozone in the chamber, and to follow ozone decay after additional ozone injection in the chamber.

When the equilibrium ozone concentration is attained, additional ozone shall be injected into the chamber in order to increase the concentration to 0,1 ppm or 3 times the stabilised value, whichever is greater, and the subsequent ozone decay measured during continuous operation of the product.

7.4.3 Interpretation

The purpose of ozone measurement is to determine the characteristic ozone emission rate of the product, and to establish concentration at the operator position.

In order to estimate ozone concentration at the operator position in practical situations, a computer simulation program shall be used to calculate ozone concentration versus time from a random set of jobs appropriate to the particular test subject. A random set is chosen for the worst case situation which is defined as 3 times the average intended use (e.g. number of copies or prints per day for a printer) for the EUT operating in the minimum allowable space with natural ventilation conservatively estimated at 0,5 ACH. The output is a peak concentration (maximum) and a mean concentration.

7.5 Particulate matter detection and analysis

7.5.1 Background

Particulate matter emissions shall be determined in the chamber during continuous operation of the EUT for a specified period, normally between 1 h and 4 h depending upon the sampling rate. The detection limit of the particulate matter concentration shall be ≤ 0,01mg/m^3.

7.5.2 Procedure

Measurements shall be corrected by means of a "blank" measurement, made before the emission measurement. The chamber shall be cleaned prior to the "blank" measurement, using a vacuum cleaner for the floor and a damp cloth for the walls and ceiling.

Airborne samples shall be collected using dynamic samplers located at four points around the EUT, the operator position and three bystander positions, all located at a height of 1,2 m above the floor and 0,3 m away from the EUT.

The chamber ventilation rate shall be adjusted to compensate for the sampling airflow rate. This is typically 1,2 m^3/h ± 5% per sampling line. The air sample shall be passed through glass fibre filters (0,7 µm pore size). The filter shall be weighed before and after sampling, using an analytical balance located in a temperature and humidity controlled room (23 °C and 50 % rH). The balance precision and the weighing conditions shall be capable of providing a lower detectable limit of less than 0,01 mg/m^3. Each filter used shall be pre-weighed before use and after test measurements are completed. An unused field blank filter shall accompany all filters used in the measurement. Weight changes due to humidity differences, etc. shall be accounted for using the field blank data. It is advisable always to weigh an unloaded filter.

7.5.3 Interpretation

The particulate matter concentration at the operator position is determined as the blank-corrected weight of particulate matter per volume of air sampled. The particulate matter concentration shall be expressed as mg/m^3.

8 Test report

The test report contents shall include the following information:

Test laboratory

- Name and address of test laboratory.
- Name of the responsible person.
- Description of the test apparatus and methods used (chamber, clean air system, environmental control, sample collection, analytical instrumentation, standard generation and calibration).

Equipment under test (EUT) description

- Type, brand name and serial number of equipment.
- Identification number (catalogue number) and lot number of consumables used.
- History of the EUT and of the consumables (date of production, date of arrival to the test laboratory, date and time of unpacking, environmental storing conditions before test).

Experimental conditions and procedures

- Chamber conditions (temperature, relative humidity, ACH).
- Equipment loading factor.
- Sampling of emitted VOC (adsorbent used, volume sampled, sampling duration and times after putting product into operation).
- Description of operating condition or conditions (modes) for EUT during test.

Data analysis

- Description of the method used to derive specific emission rates from measured chamber concentrations.

Results

- Specific emission rates shall be reported for each product for individual VOC and TVOC, at the times of air sampling after putting the product into operation.

Quality assurance and quality control

- Background chamber concentration of target compounds.
- Recovery data of target compounds (to evaluate sink effects).
- Results of duplicate sampling/analysis.
- Quality of the environmental chamber variables (temperature, relative humidity, ACH).

9 Quality assurance and quality control

Chamber testing of chemical emission from electronic products shall be conducted within the framework of a Quality Assurance Project Plan (QAPP).

The QAPP shall contain the following elements:

9.1 Data quality acceptance criteria

This section of the QAPP defines the precision, accuracy, and completeness targeted for each parameter being measured.

9.2 QA/QC approaches and activities

QA/QC activities shall be specified in the QAPP to include establishment of a system of records/notebooks that ensures proper operation of equipment and recording of data. Such activities can include:

- Sample log to record receipt, storage and deposition of equipment under test.
- GC-standards preparation log to document preparation of all organic compounds.
- Permeation tube log to record weight loss data for all permeation tubes.
- Calibration logs containing environmental systems calibration data.
- Instrument maintenance logs to document maintenance and repair s of all equipment.
- Sample testing logs in which to record all pertinent information for each test, including sample details, EUT ID number, and GC run ID number.
- Sorbent cartridge cleanup desorption log detailing thermal cleanup and QC validation of cartridges.
- Disk storage log to document location and content of electronically stored data.
- Manuals governing operation of all equipment used by the project.

Project staff shall carry out QC activities in a routine, consistent manner to provide necessary feedback in operation of all measurement systems. Such activities can include:

- Routine maintenance and calibration of systems.
- Sample log to record receipt, storage and deposition of equipment under test.
- Daily recording of GC calibration accuracy and precision (i.e. control charting).
- Timely monitoring of percent recovery of the internal standard that was added to all samples.
- Collection and analysis of duplicate /triplicate samples.

- QC checking of organic collection sorbent tubes.
- Periodic analysis of audit gases supplied by an independent source.
- Participation in interlaboratory comparisons on product/material emission measurements and chemical analysis.

9.3 QA/QC Audits

Finally, the QA/QC program shall include periodic audits by QA personnel to evaluate compliance with QAPP protocols.

Annex A
(informative)

VOC build up in a chamber

An EUT is placed in a chamber at time t = 0. At any time, for each VOC, the following mass balance holds:

$$V\frac{dc}{dt} = E - q_{out}c + q_{in}c_{in} \qquad (1)$$

Where:

c	VOC concentration [mg/m^3].
t	Time [min]
V	Chamber air volume [m^3]
E	VOC emission rate [mg/min]
q_{out}, q_{in}, q_{room}	Chamber ventilation [m^3/min]
c_{in}	VOC in ventilation air [mg/m^3]

It is assumed that the chamber is mixed homogeneously, so that the VOC concentration does not vary within the chamber. Furthermore it is assumed that the emission rate E of the VOC from the EUT is constant with time.

Integrate, with at t = 0 : c = c_0:

$$c = \frac{E}{q_{room}} + c_{in} + \left(c_0 - c_{in} - \frac{E}{q_{room}}\right)\exp\left(\frac{-t}{V/q_{room}}\right) \qquad (2)$$

If $c_0 = 0$ and $c_{in} = 0$, (2) reduces to: (*non-equilibrium*)

$$c = \frac{E}{q_{room}}\left(1 - \exp\left(\frac{-t}{V/q_{room}}\right)\right) \qquad (3)$$

This equation can be rewritten as:

$$c = \frac{E}{VN_a}\left[1 - \exp(-N_a t)\right] \qquad (4)$$

$N_a = \frac{q_{room}}{V}$ is the air exchange rate per minute.

This is the number of air changes per minute.

In the diagrams below, instead of N_a, the air exchange rate per hour, or ventilation rate, is used: $V' = 60N_a$.

For very large t, (3) reduces to: (*equilibrium*)

$$c_{eq} = \frac{E}{q_{room}} = \frac{E}{VN_a} \qquad (5)$$

In diagram A.1, is depicted the concentration, normalized to reach an end concentration of 1 (arbitrary units) as a function of time, after the start of an experiment. The air exchange rate (V') of the chamber is a parameter.

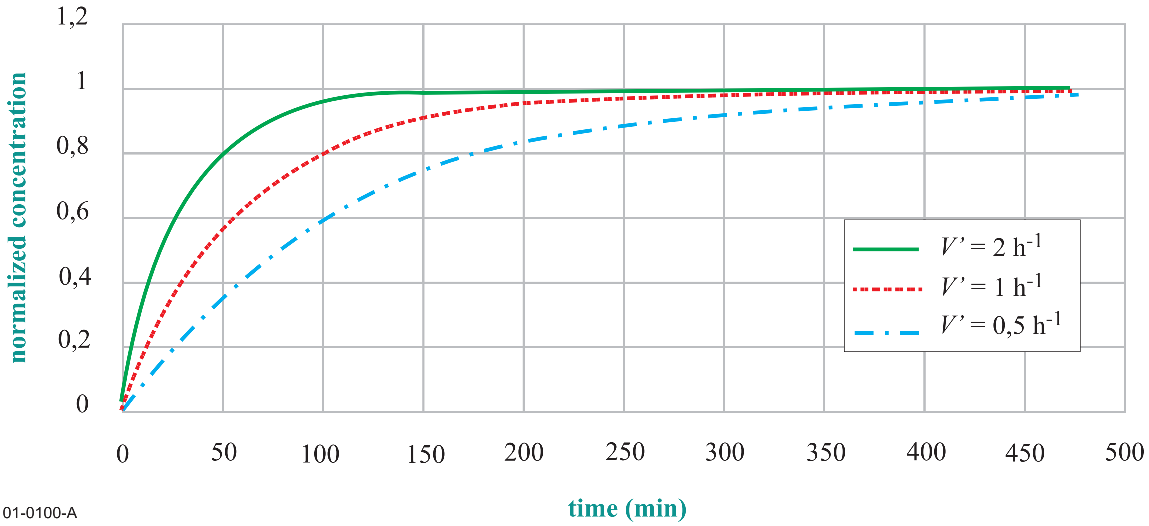

Diagram A.1 - VOC build-up

How long it will take to "reach equilibrium", depends on the deviation from equilibrium that one judges as acceptable. As a measure for equilibrium one can assume for instance the 95% value or more accurately the 99% value. For a few cases, this is summarized in table A.1.

Table A.1 – Summary of time to reach equilibrium

Time (min) to	V'=0,5 (h^{-1})	V'=1,0 (h^{-1})	V'=2,0 (h^{-1})
95% equilibrium	360	180	90
99% equilibrium	553	277	138

Note that it is the air exchange rate only, which determines the time to reach a 95% value or a 99% value. When the chamber air has been replaced 4 times by ventilation, this implies that a concentration has been attained which is 98,2 % of the equilibrium concentration. This can be viewed as quasi-equilibrium.

Diagram A.2 illustrates the actual difference in absolute concentration of VOC for an example with an emission rate of E = 1 µg/min and a chamber capacity of 30 m^3, and air exchange rates of 0, 0,5, 1 and 2 h^{-1}.

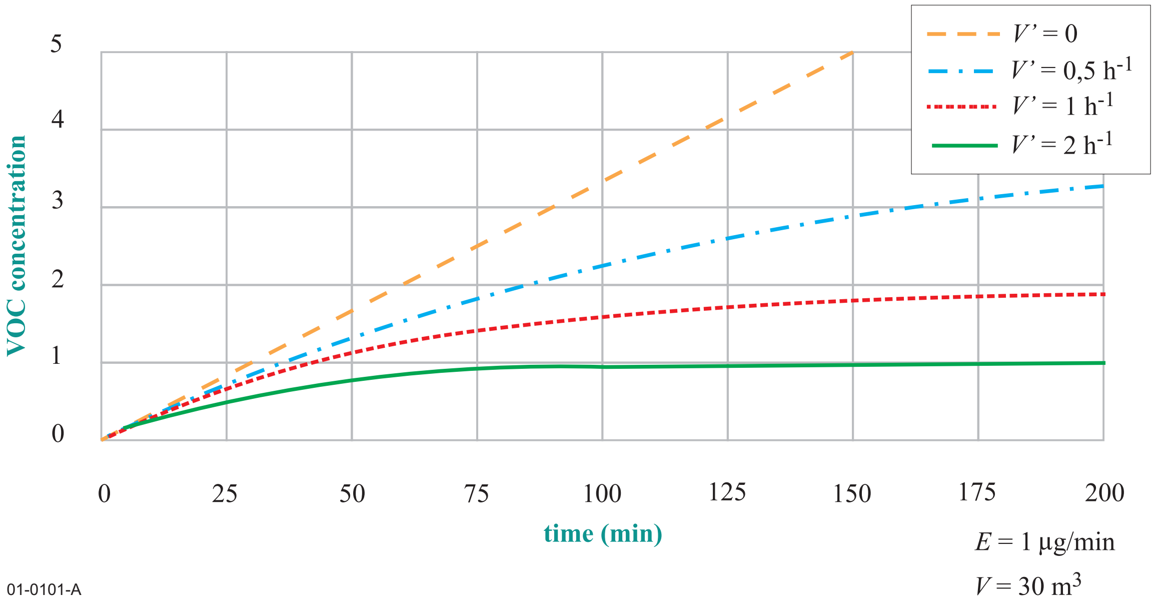

Diagram A.2 – VOC build-up, V' as a parameter

Because a sample of VOC is taken over a period of time, by passing air over a sorbent, a time-averaged concentration of the VOC in the air is determined.

So from the formula given for the *non-equilibrium case* (4), which relates the *end concentration* of VOC to the elapsed time, a formula has to be deduced for the *time-averaged concentration* of the VOC.

The average concentration is by definition, integrating from start time t_0 (t = 0) until end time $t = t_e$:

$$< c > = \frac{1}{t_e - t_0} \int_{t_0}^{t_e} c \, dt \qquad \textbf{(6)}$$

By substituting (4) in (6) and integrating, yields:

$$< c > = \left(\frac{E}{V N_a} \right) \left[\left(\frac{1}{N_a t} \right) \left(1 - \exp\left(- N_a t \right) \right) \right] \qquad \textbf{(7)}$$

NOTE
In the formula $t = t_e - t_0$ has been substituted back. The formula does not apply to $V' = 0$.

The relation between <c> and c is given by:

$$c = \left(\frac{E}{V} - < c > N_a \right) t \qquad \textbf{(8)}$$

For the normalised case diagram A.3 illustrates the relation between the end-VOC and the average-VOC concentration (air exchange rate $V' = 1\ \mathrm{h}^{-1}$).

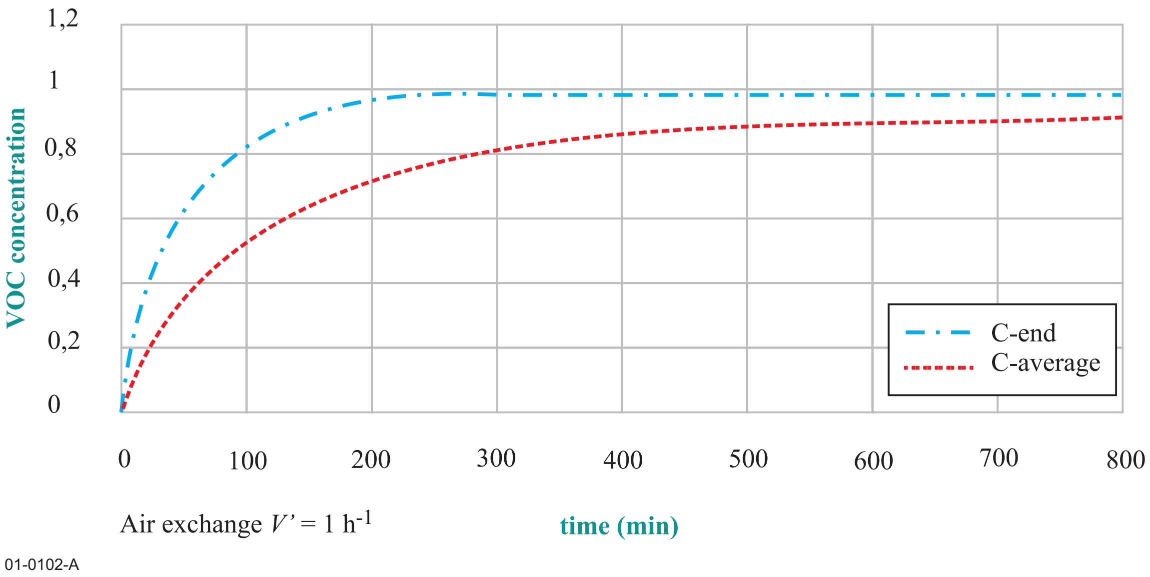

Diagram A.3 – VOC end concentration versus average concentration

In an analogous manner an average concentration can be calculated when sampling starts at t > 0.

Practical considerations

Probably the most important aspect is whether consumables are used by the EUT or not. If consumables are used, and the consumables are the major source of VOC, then it is justified to say that the product can be regarded as a constant emission source of VOC under continuous use of the product.

On the other hand, if consumables are not used, the emission of VOC may decrease from an initial relatively high value to a lower value over time. The associated time constant however will be rather large (weeks, months), which implies that the theoretical approach given above may also approximately be applied to this case.

VOC may decrease in concentration by condensation, adsorption or reaction. The consequences of these effects are not incorporated in the preceding section.

As it can be seen from the theoretical section, the non-equilibrium approach is probably more prone to error, but the advantage over the equilibrium approach is the possibility of a shorter test-time.

The inability in practice to exactly start at $t = 0$ may lead to errors in the non-equilibrium case. (when the EUT under test is switched on; it must also be noted that VOC are emitted from the moment when the EUT is placed in the chamber)

It is possible that, after switching on the EUT, some VOC may be emitted in different amounts initially until the EUT is fully “heated up”.

Annex B
(informative)

Bibliography

ISO 7708:1995 International Organization for Standardization - Air Quality - Particle size fraction definition for health related sampling.

ISO/DIS 16017-2 International Organization for Standardization - Indoor, ambient and workplace air - Sampling and analysis of volatile organic compounds by sorbent tube/capillary gas chromatography - Part 2: Diffusive Sampling.

ISO / DIS 14021 1999 International Organization for Standardization - Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling).

Australia CSIRO - Assessment of Pollutant Emissions from Dry-process Photocopiers in: Engineering Solutions to Indoor Air Quality Problems, Air & Waste Management Association, Pittsburgh, pp 61-70

Blue Angel (Germany) RAL-UZ 62 Copiers; RAL-UZ 85 Printers RAL-UZ 95 Fax Machines, Telecopiers and Combined Machines RAL Deutsches Institut für Gütesicherung und Kennzeichnung e.V. [German Institute for Quality Assurance and Labelling], Bonn, Germany, see also: http://www.blauer-engel.de/English/index.htm

California Prop 65 - Safe Drinking Water and Toxic Enforcement Act of 1986, California Health and Safety Codes 25249.5 - 25249.12

UL 2117Underwriters Laboratories Inc. - Draft Standard for Indoor Emissions of Equipment.

CEN - ENV 13419-1 Comité Européen de Normalisation - Building products - Determination of the emission of volatile organic compounds - Part 1 Emission test chamber method.

CEN - prENV 13419-3 Comité Européen de Normalisation - Building products - Determination of the emission of volatile organic compounds - Part 3 Procedure for sampling, storage of samples and preparation of test specimens.

ASTM D5116-90 America Society for Testing and Materials - Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products - 1990.

ASTM D6245-98 American Society for Testing and Materials - Standard Guide for Using Indoor Carbon Dioxide to Evaluate Indoor Air Quality and Ventilation - March 10, 1998.

AQS 150Air Quality Sciences, Inc. - Chamber Evaluation of Office Machines - Protocol for Environmental Chamber Evaluation of Office Machines for Emissions of TVOC, IVOCs, Particulates and Ozone.

Ecolabelling of Copying Machines Criteria document 10 December 1997 - 9 June 2002 Version 2.2; see: http://www.ecolabel.no/ecolabel/english/criteria.html

Ecolabelling of Printers and Fax Machines Criteria document 14 June 1999 - 13 June 2001 Version 2.0; see: http://www.ecolabel.no/ecolabel/english/criteria.html

EPA Compendium Method TO-11A - Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography

European Collaborative Action. 1991. Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. Report No. 8. EUR 13593 EN. Luxembourg: Office for Official Publications of the European Communities.

European Collaborative Action. 1993. Determination of VOCs emitted from indoor materials and products, Interlaboratory comparison of small chamber measurements Report No. 13. EUR 15054 EN. Luxembourg: Office for Official Publications of the European Communities.

European Collaborative Action. 1997. Evaluation of VOC emissions from building products (solid flooring materials) Report No. 18. EUR 17334 EN. Luxembourg: Office for Official Publications of the European Communities.

NITO document: "Eco declaration (DK, NO, SE)". (Copyright Swedish IT-companies' Organisation); http://www.itforetagen.se/

US EPA EVT - Large Chamber Test Protocol For Measuring Emissions of VOCs and Formaldehyde -US EPA Large Chamber Test Protocol for Measuring Emissions of VOCs and Formaldehyde ("Standard Emissions Testing Guidance for Dry-Process Photocopy Machines")

Tichenor, B.A. Indoor Air Sources; using small environmental test chambers to characterise organic emissions from indoor materials and products, EPA -600 8-89-074, Air and Energy Research laboratory, U.S. Environmental Protection Agency, 1989

TUEV Nord - Wensing, M.: Determination of Organic Chemical Emissions From Electronic Devices in: Proceedings Indoor Air 99 (8th International Conference on Indoor Air Quality and Climate, Edinburgh, Scotland 8-13 August 1999, Volume 5 page 87-92

Verband der Automobilindustrie, VDA [German Automobile Industry Association] VDA recommendation 276 (Draft version November 1999) Part 1: Determination of organic substances emitted from automotive interior products using a 1 m² test cabinet. Part 2: Automotive interior moulded parts, Determination of the release of Formaldehyde, Ammonia and Phenol - measurement method using a 1 m³ test cabinet. Frankfurt , 1999

VDI Guideline 3862 Part 3: Gaseous emission measurement – Measurement of aliphatic and aromatic aldehydes and ketones by DNPH method cartridges method, Düsseldorf, Germany, 12/2000

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